

# THE AMERICAN MINERALOGIST

JOURNAL OF THE MINERALOGICAL SOCIETY OF AMERICA

Vol. 21

MARCH, 1936

No. 3

## MINERALIZATION OF THE VIRGINIA TITANIUM DEPOSITS\*

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The Virginia titanium deposits are the world's largest producers of rutile and also contain large supplies of ilmenite. The producing district lies in the central part of the State, about midway between Charlottesville and Lynchburg. It is part of the Piedmont region but lies near the base of the Blue Ridge whose crest is about 12 miles to the northwest.

A study of these titanium deposits has led to the conclusion that they are not magmatic segregations, but have been formed by invading solutions. It will not be possible to give many of the details of occurrence, of mineralogy, and of chemical relationships in a brief paper of this character. However, these will all be included in a more comprehensive report which is planned for later publications by the United States Geological Survey. This paper will present briefly the evidence that indicates the mode of origin and some of the outstanding factors in the chemistry of mineralization.

The dominant country rock of the region is a gneissic quartz monzonite of pre-Cambrian age which has been intruded by a feldspathic rock that was originally composed only of andesine, which contained microscopic lenses of antiperthitic microcline. This intrusive mass is roughly elliptical in shape, being about 13 miles long,  $2\frac{1}{2}$  miles in greatest width, and having a total area of about 22 square miles. It is composed of feldspar which everywhere shows a cataclastic structure. Most of it has been very thoroughly granulated, but locally masses up to six inches in diameter have partly escaped granulation. This primary feldspar is light blue-grey in color and contrasts strongly with the white granulated material. After granulation the rock was intruded by a group of ferromagnesian dikes, by numerous small lenses of ferromagnesian minerals, and by quartz.

The contact of the feldspathic intrusive with the country rock is

\* Presidential address presented at the sixteenth annual meeting of the Mineralogical Society of America, New York, N.Y., December 27, 1935.

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marked by a broad zone of injection, or augen gneiss. This injected material seems to represent residual magma forced out of the spaces between the grains of the partly crystallized rock, by filter press action, during intrusion and consolidation. The mono-mineralic character, the intrusion as a mush of crystals, the thorough granulation, and the expulsion of residual magma, all show the relationship of the Virginia rock to typical anorthosites. It differs from these only in the more sodic character of its plagioclase, and therefore the name anorthosite seems to be applicable to this feldspathic intrusive.

The titanium deposits are of two types—one as disseminations in the anorthosite, and the other as lens- or dike-like bodies of a rock called nelsonite. The disseminated ores are all within the anorthosite, as are most of the nelsonite bodies. A few small nelsonite bodies have intruded the country rock.

The disseminated ores are most readily studied in the open cut mine of the American Rutile Company at Roseland, where they are associated with a series of parallel shear zones. Close to these, ilmenite occurs, associated with actinolite, clinozoisite, and biotite. Rutile becomes the dominant titanium mineral in an intermediate zone, where it is associated with tremolite, sericitic muscovite, and clinozoisite. At greater distances—indeed throughout the anorthosite—muscovite and clinozoisite have developed. The mines at Roseland also contain large irregular masses of a blue-grey quartz, for which the district is noted. The color is due to great numbers of minute rutile crystals that are included in the quartz. It forms irregular masses up to a foot or more in diameter, or more rarely definite veins. These masses of quartz tend to be associated with zones where there has been shearing and where ferromagnesian minerals are most abundant. Thus there is a clear relationship between quartz and other secondary minerals.

The nelsonite bodies are composed essentially of rutile or ilmenite, and apatite, but commonly gangue silicates are also present. The nelsonite body being worked by the Southern Mineral Products Company contains some "hard ore" which is about one-third apatite and two-thirds ilmenite. More generally the rock contains varying proportions of ilmenite and apatite, which are associated with biotite, or less commonly with fine grained actinolite. Within the nelsonite body is a large "horse" of typical anorthosite, which has been only slightly mineralized, and contains but a few per cent of ilmenite, apatite, actinolite, micas and clinozoisite. On its border this mass shows a gradual transition to a lean biotited nelsonite. Other bodies contain large proportions of amphiboles associated with apatite, ilmenite, and garnet, and also numerous residual areas of anorthosite.



The titanium minerals and the associated secondary silicates in both types of deposits are believed to have been formed by invading solutions. Evidences of replacement and secondary origin are as follows. The rutile and ilmenite of the disseminated deposits occur only in the granulated portions of the anorthosite, and are totally absent in primary feldspar. Titanium minerals are localized near major fractures which evidently acted as feeders for mineralizing solutions. The distribution of titanium minerals is exceedingly erratic, and varies from rich to barren rock within a few feet. Ilmenite occurs in fractures and cleavage planes in hypersthene which has formed in the parallel shear zones in the anorthosite. Thus both hypersthene and its enclosed ilmenite are later than the anorthosite. The rutile and ilmenite are ungranulated, even where included in thoroughly granulated feldspar. Ilmenite and the same associated silicates that occur in the anorthosite are also found in the country rock along the borders of the anorthosite where only solutions seem capable of introducing them.

The nelsonite bodies show a sequence of mineralization. Reaction rims of garnet surround small residual areas of anorthosite in some occurrences. Apatite is the earliest of the secondary minerals, followed by rutile or ilmenite, which in places form veinlets in the apatite. Biotite forms veinlets in apatite, rutile, and ilmenite. In both the disseminated deposits and in the nelsonites, rutile has been replaced by ilmenite, and magnetite forms veinlets in ilmenite, thus showing a sequence in the composition of the depositing solutions. Post granulation dikes are highly altered, evidently at the same time as the enclosing anorthosite, and contain abundant ilmenite.

Small veins of nelsonite have formed along fractures in the anorthosite in specimens from the mine of the American Rutile Company and from the dumps of the old General Electric Company mine. The pyrogenic origin that has commonly been assumed for the Virginia deposits implies two distinct periods of formation. The disseminated deposits would represent a crystallization from a feldspathic magma, whereas the nelsonite would represent a much later crystallization from an exceedingly basic magma that intruded the earlier one after it was consolidated and fractured. On the other hand, deposition from incoming solutions avoids the improbable assumption of two distinct periods of formation for essentially similar groups of minerals.

Mineral deposits are in general characterized by diverse groups of minerals that have been introduced into rocks of complex chemical composition. In contrast, the Virginia titanium deposits have replaced a rock of very simple composition. The important introduced elements are limited in number and were totally absent in the primary rock. These

relations present an unusually favorable opportunity for studying the chemistry of mineralization.

The physico-chemical factors that control mineral alterations and replacements are in general complex, and inadequately known. In the titanium region, however, the instability of calcic plagioclase and the stability of sodic plagioclase in the presence of hydrous solutions seems to have been the dominant factor in mineralization. This instability and some of its consequences have been discussed by Bowen in the *Lindgren volume*.<sup>1</sup> The reaction principle is, no doubt, the controlling factor in a wide variety of hydrothermal processes just as in magmas, and the Virginia titanium deposits probably differ only in the clearness with which the reaction principle control of mineralization is indicated.

Recently Eskola<sup>2</sup> has experimentally produced the alteration of calcic to sodic plagioclase in solutions containing an excess of sodium carbonate and silica. He found that albitization was more complete, and the resulting crystals more perfect at 310° to 330° than at 550° or even at 360°. Highly sodic albite developed only at the lower temperatures. In the titanium deposits the reactions between the anorthosite and the incoming solutions has produced plagioclase feldspar ranging in composition from andesine to albite. Thus Eskola's work suggests temperatures ranging down to at least 300° during mineralization in the Virginia deposits.

The primary anorthosite was composed of approximately 3 parts of andesine and 1 of microcline. That is, 2 molecules of albite, 1 of anorthite, and 1 of microcline, or chemically only of  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{CaO}$ ,  $\text{K}_2\text{O}$  and  $\text{Na}_2\text{O}$ . In the innermost zone of alteration ilmenite, actinolite, biotite, and clinozoisite formed showing the introduction of  $\text{TiO}_2$ ,  $\text{FeO}$  and  $\text{MgO}$ . Throughout the anorthosite the new minerals were muscovite, clinozoisite and sodic plagioclase which are composed of  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{CaO}$ ,  $\text{K}_2\text{O}$  and  $\text{Na}_2\text{O}$ , the same elements comprising the anorthosite. This implies zonal relations, with titanium, iron and magnesium as the essential new elements that were introduced into the zone of most intense alteration. The solutions evidently lost most of their iron before reaching the intermediate zone, and only insignificant amounts of these three elements penetrated into the great mass of the anorthosite. The inner zone which is characterized by titanium minerals and iron bearing silicates is very irregular in width, but in general ranges from a few feet up to perhaps 15 or 20 feet before it gradually merges with the second, or nearly iron free zone. This second zone is wider than the last, and was controlled

<sup>1</sup> Bowen, N. L., Ore deposits of the Western States: *Lindgren volume*, p. 114, 1933.

<sup>2</sup> Eskola, Penetti, An experimental illustration of the spillite reaction: *Compt. Rend. Soc. Geol. de Finlande*, Extract No. 9, pp. 1-8, 1935.



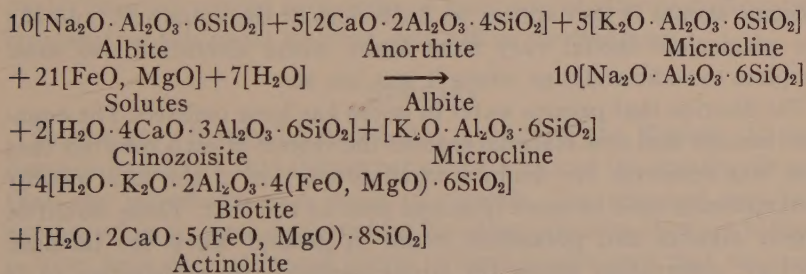
by the permeability of the granulated rock as well as by proximity to feeding channels. In places it probably has a width of some hundreds of feet before it fades out into the altered but nearly unmineralized portion of the anorthosite.

We may now examine these changes by means of chemical equations, neglecting the rutile and ilmenite which were introduced into the anorthosite by the complete removal of the feldspar in the space they occupy. This type of replacement involves relative solubilities, and probably other factors that can not be evaluated and so can not be represented by simple equations.

In the following chemical equations the name of the mineral represented is placed immediately below its chemical formula. The mineral molecules of the original rock, and the introduced solutes precede, and the new minerals formed by the reactions follow the arrow. The proportion of the albite, anorthite and microcline molecules comprising the original anorthosite are fixed in approximately the ratio 2:1:1 and so when the same molecules reappear among the new minerals on the right of the equation they are not canceled. The proportion of the new elements introduced as solutes is determined by balancing the equation, but their character is clearly indicated by the new minerals formed. Some of the secondary minerals—notably amphiboles and micas—do not have definite formulas. However, variations in their composition introduce only slight changes in proportions and do not affect fundamental relations. The following equations are representative of chemical reaction in the three zones of mineralization.

Equation No. 1 represents the inner zone of most intense alteration. The new elements introduced form only about 10 per cent of the resulting rock, although there has been a very thorough change in the mineral composition.

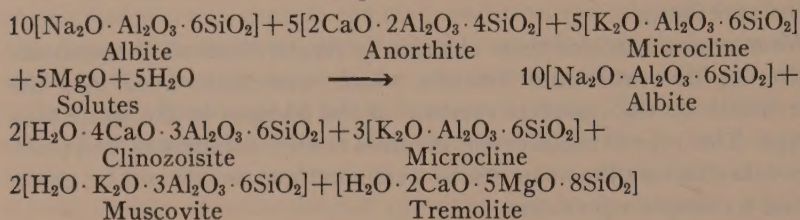
#### Equation No. 1



Equation No. 2 represents the intermediate zone where about 2.5 per cent of new material has been added and a slightly smaller proportion

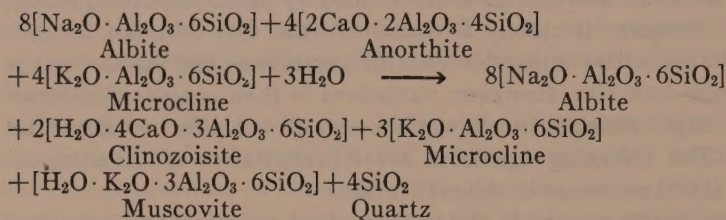
of new minerals developed than in the zone represented by the last equation.

## Equation No. 2



Equation No. 3 represents relations throughout the anorthosite. Here only a little water has been introduced, and a marked change in mineral composition has been produced merely from a re-arrangement of the materials of the primary rock. Albite and the elements that recrystallized into clinozoisite were released from the andesine, and some of the microcline has formed muscovite.

## Equation No. 3



These equations are no doubt a simplification of the chemical processes within the anorthosite. The rock itself shows incomplete alteration of feldspar to new minerals and much of the plagioclase has become only moderately more sodic. Thus varying proportions of the anorthite molecule should in fact appear on both sides of the equations, and the new plagioclase should vary from albite where alteration was most complete to sodic andesine where it was less so.

The fluorine that proxies water in micas has been omitted. The equations assume that new material entered the system in each zone but that none was removed. No doubt a small proportion of the least readily fixed elements tend to move from one zone to the next. These would be largely alkalis and potassium would in general move the farthest. Geologic observation shows the strong tendency for albitization to fix sodium and drive out potassium.

Such equations as these obviously can not fully represent chemical relations, but nevertheless they seem to present an approximate and



significant picture of the chemistry of mineralization in the Virginia deposits. They enable us to visualize the reactions, and indicate that these were less complex than might otherwise be assumed. They also show that the simplest possible re-arrangement of  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{CaO}$ ,  $\text{K}_2\text{O}$  and  $\text{Na}_2\text{O}$  plus incoming  $\text{H}_2\text{O}$  into new groupings results in the three minerals albite, muscovite and clinozoisite.

The evidence of a simple recrystallization presented by equation No. 3 suggested the desirability of analyzing material that had undergone extreme alteration for comparison with an analysis of the unaltered primary feldspar that had previously been made. A specimen showing a maximum proportion of albite, muscovite, and clinozoisite was selected and the two analyses are given in the following table.

CHEMICAL ANALYSES OF FRESH AND ALTERED FELDSPAR

	Fresh	Altered
$\text{SiO}_2$	61.44	59.62
$\text{Al}_2\text{O}_3$	23.47	24.06
$\text{Fe}_2\text{O}_3$ } as FeO	0.20	0.49
FeO		0.09
MgO	0.05	0.07
CaO	5.00	4.54
$\text{Na}_2\text{O}$	5.94	5.47
$\text{K}_2\text{O}$	3.92	4.53
BaO	0.19	n.d.
$\text{H}_2\text{O}-$	0.03	0.03
$\text{H}_2\text{O}+$	0.20	1.19
$\text{TiO}_2$	0.10	0.09
	100.54	100.18

These analyses are strikingly similar. Sodium and calcium are a little lower and potassium a little higher in the altered rock, and water and a little ferric iron have been introduced. Otherwise the two rocks are essentially the same. As suggested before, a little potassium has evidently been introduced from zones of more intense alteration. Equations representing this could be given, but will be omitted here.

#### SUMMARY

In summary it may be stated that a study of the Virginia titanium deposits has shown that they occur within a rock of the anorthosite type that was introduced as a mush of crystals. The ores and associated gangue minerals were deposited by invading solutions that are believed to have been derived from a highly ferromagnesian rock that was probably a differentiate from the same primary magma as the anorthosite. Some of the chemical factors of mineralization are indicated and prove to be rather simple in character.

# A TECHNIQUE FOR THE CONSTRUCTION OF MODELS ILLUSTRATING THE ARRANGEMENT AND PACKING OF ATOMS IN CRYSTALS

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## INTRODUCTION

Recent developments have demonstrated that the vast accumulations of empirical knowledge in theoretical mineralogy and crystallography have rational explanations in the manner of arrangement of the constituent atoms in the crystals. This is not only the case regarding data bearing on what are generally considered the physical and chemical properties of crystals, but it is now also clearly indicated with regard to the external morphology or crystal habit as well.

In order to make intelligent use of the data developed by crystal structure investigations, it is necessary to obtain correct visual pictures of the structures themselves. Data in the form of cell dimensions, space group, and atomic coordinates are of very little use in this connection. Projections or drawings of the structures are more useful, but usually serve to display only certain features. Three dimensional models alone give true insight into the intricacies and interrelationships of even relatively simple structures. Their value in research in theoretical mineralogy cannot be too greatly stressed, and by the same token truly modern mineralogy can hardly be taught without their aid.

Methods for the construction of models illustrating the arrangement of atoms in crystals have been described by Wyckoff and Ksanda<sup>1</sup> and by Gruner.<sup>2</sup> Neither of these methods gives any idea of the packing of the atoms in the structures.

Several years ago a general method for illustrating both arrangement and packing of atoms in crystals was developed in this laboratory. After considerable experimentation and improvement, especially in some of the minor details of the routine, a very workable technique for the construction of such models has been evolved. It is believed that a neat, strong, packing model of any crystal structure can be made by this method no matter how complicated the structure, provided only that, in the case of the complicated arrangements, the time and labor spent on calculation and construction are worth the effort.

<sup>1</sup> Wyckoff, Ralph W. G., and Ksanda, C. J., A simple model for illustrating the atomic arrangements in crystals: *Am. Jour. Sci.*, 5th series, vol. 11, pp. 377-380, 1926.

<sup>2</sup> Gruner, John W., A new method of building crystal structure models: *Am. Mineral.*, vol. 17, pp. 35-37, 1932.



It is now pretty clearly established that atoms in crystals behave as if they were rigid or semi-rigid spheres in contact. The radius of such a sphere is constant, or very approximately so, in all cases in which the atom has the same electronic state and coordination, but differs with a change of these internal and external conditions. These radii are listed in standard references.<sup>3,4,5</sup> Models of crystal structures may therefore be constructed of spheres of appropriate sizes bonded together in positions to correspond with those indicated by the coordinates of the atoms established by  $x$ -ray investigations. The technique developed in this laboratory consists of pinning balls together by means of metal pins. Because of easy workability, wooden balls, painted to represent various atomic species, have been employed.

### GENERAL TECHNIQUE

#### OUTLINE OF PROCEDURE

Given the data furnished by the crystal structure investigator, it is necessary, in general, to proceed by a series of distinct steps, taken in correct sequence, in order to construct a packing model of the structure. These steps are as follows:

1. Calculation of the atomic environments in the actual crystal.
2. Adjustment of atomic environments to available material.
3. Calculation of drilling coordinates.
4. Painting the balls.
5. Drilling the balls.
6. Assembling the model.

In the following section each of these steps will receive detailed consideration and in a subsequent section illustrations of the principles involved will be given by means of representative examples.

#### CALCULATION OF THE ATOMIC ENVIRONMENTS IN THE ACTUAL CRYSTAL

Before it is possible to proceed, the general plan of the structure must be grasped. This is sometimes illustrated in original papers; frequently it is not. Fortunately, the excellent illustrations in *Strukturbericht*<sup>6</sup> and

<sup>3</sup> Goldsmidt, V. M., *Geochemische Verteilungsgesetze der Elemente*, vol. 7: *Skrifter utgitt av Det Norske Videnskaps-Akademi i Oslo I. Matem.-Naturvid. Klasse*, No. 2, 1926.

<sup>4</sup> Wyckoff, Ralph W. G., *The Structure of Crystals*, 2nd ed.: pp. 192-193, New York, 1931.

<sup>5</sup> *International Tables for the Determination of Crystal Structures*, 2nd vol.: pp. 610-616, Berlin, 1935.

<sup>6</sup> Ewald, P. P. and Hermann, C., *Strukturbericht: 1913-1928*; Supplement to *Zeit. Krist.*, 1931.

Wyckoff's book<sup>7</sup> usually provide sufficient information to reveal the plan of the structure for crystals whose structures have been known long enough to be included in these two standard references.

The plan having been grasped, the first step is to calculate the interatomic distances of the nearest neighbors of each kind of atom present. For structural types which have appeared early enough to be included in *Strukturbericht*, the coordinates of the atoms are listed in tables entitled, *Raumgruppentabelle*. The components of interatomic distances in terms of cell dimensions may be found in tables entitled, *Nachbarschaft*, to be used in conjunction with the stereographic projection, *Nachbarschaftsbild*, of the environment of the atom in question. In the latter projection the largest circles indicate nearest neighbors, the sizes decreasing with increasing distance. These circles are lettered to correspond with the components of interatomic distances given in the tables. *Strukturbericht* provides another table, entitled, *Substanztabelle*, in which the cell dimensions and atomic parameters together with numerical values of certain of the important interatomic distances are given for important representatives of the structural type.

When the information regarding interatomic distances cannot be obtained from *Strukturbericht* or the original article, it is necessary to calculate them from knowledge of the space group symmetry operations, cell dimensions, and parameters of the atoms as determined by the structure analysis, and available usually only in the paper describing the original investigation. Often it is possible to make the entire computation of interatomic distances graphically on a large scale with sufficient accuracy for subsequent requirements. Under any circumstances, a graphical solution is recommended as a check on the analytic geometric computations.

The calculation of interatomic distances by analytic methods is based upon the familiar relation that if the coordinates of two points, 1 and 2, referred to an orthogonal, isometric coordinate system, are  $x_1, y_1, z_1$  and  $x_2, y_2, z_2$ , their distance apart is,

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}.$$

The coordinates  $x, y, z$  of an atom may be expressed in terms of the unit cell dimensions and angles, the parameters of the atom, and the space group operations.

It cannot be too strongly emphasized that in any but the simplest structures, it is essential to understand the space group before computations for a structure can be undertaken, and even with the computations

<sup>7</sup> Reference 4, part II; also, Wyckoff, R. W. G., *The Structure of Crystals*: Supplement for 1930-1934 to the 2nd ed., New York 1935.



carried out as they are in many cases in *Strukturbericht*, a knowledge of the space group is essential to enable one to assemble the structure. An important point in this connection concerns the matter of right- and left-handed units. Atoms or other units related to one another in the space group by operations of the first sort (translations, rotations, screws) are both right-handed or both left-handed, while if the space group operations of the second sort (inversions, reflections, glide-reflections) relate them, they have opposite senses. This implies also that their environments are related in this manner, and therefore the ball drillings and ball assemblies must take into account both right-handed and left-handed analogues in the latter instance, except under special conditions. Failure to recognize this results in considerable confusion.

#### ADJUSTMENT OF ATOMIC ENVIRONMENTS

After the interatomic distances of neighboring atoms have been calculated as above, it is possible to select balls of appropriate size to represent the atoms to scale. Because of convenience and considerations of availability and cost of material, the writers have chosen to build models to the scale of 1 inch = 2 Å. This brings the required ball diameters to between about  $\frac{1}{4}$  inch and 2 inches, with the great majority of atoms centering around a value in the region of  $1\frac{1}{4}$  inches, a very convenient dimension from several standpoints.

The sizes of the atoms in a given crystal structure are not often mentioned by the author of a paper describing the structure, partly because an individual structure may in itself give no clue to absolute sizes. The sizes can be determined, however, by a number of methods. In the first place, there are certain definite sizes to be expected for a given atomic species in a given electronic and coordination condition, from which sizes the atoms deviate but little from structure to structure. Such sizes are listed in tables.<sup>3,4,5</sup> Ordinarily, however, they are not sufficiently accurate for use in a model of any given structure, and internal evidence may be usually found in each structure for refining the values somewhat. The values for the sizes of the atoms in a crystal can be had if the crystal has an atom, *A*, one of whose closest neighbors is another atom of the same species, *A*. The radius of *A* is then half the interatomic distance of this *A:A* pair. The radius of *A* being established, the radius of any other atom, *B*, which also is a closest neighbor to *A*, can be had by subtracting the radius of *A* from the interatomic distance *A:B*.

If the structure provides no atoms in pairs, it is then necessary to utilize expected radius values as they stand. When this is done, it will be found, in general, that the sum of these radii does not correspond

exactly with values required for the interatomic distances as calculated in the foregoing sections. In such instances, it is necessary to make adjustments of the standard radii either arbitrarily or based on past experience so that the interatomic distances come out approximately correct. Ordinarily, one tries to keep the ratio of the standard radii unaltered in making them fit the actual interatomic distance. This is the first kind of adjustment.

A second kind of adjustment is necessary in instances of an atom *A* surrounded by several atoms *B* at very nearly, but not quite, the same distance. In order to utilize spherical balls, it is necessary to adjust the actual position of the *A* atom so that all the *B* atoms are at the same distance, at the same time keeping all other features of the structure as nearly true as possible.

A third kind of adjustment is often necessary if the structure contains more than two species of atoms. In such cases if the interatomic distances from species *A* to *B* are satisfied by a pair of radii selected for *A* and *B*, and then the radius of *C* is chosen to give the correct interatomic distance *AC*, it frequently happens that the radius of *B* plus the radius of *C* turns out to be incompatible with the distance *BC* in the structure. This is because the atoms were assumed to be exactly spherical and in contact, which is an approximation. By slight adjustments of the positions of *A*, *B*, and *C*, the distances *AB*, *AC*, and *BC* may be made consistent.

A fourth kind of adjustment is necessary if the actual radii, as calculated and adjusted above, are found to require balls of sizes not available commercially. Wooden balls are available in diameters ranging from  $\frac{1}{4}$  inch to  $2\frac{1}{4}$  inches by steps of  $\frac{1}{8}$  inch, i.e., in radius intervals of  $\frac{1}{16}$  inch.<sup>8</sup> Interatomic distances can therefore only be approximated to

<sup>8</sup> Obtainable from Newton & Thompson Mfg. Co., Brandon, Vermont. Prices quoted May 24, 1935, to the writers are as follows:

<i>Ball diameter</i>	<i>Price/M in lots of 5M</i>
$\frac{3}{4}$ "	\$ 1.50
$\frac{7}{8}$ "	1.80
1 "	2.50
$1\frac{1}{8}$ "	3.25
$1\frac{1}{4}$ "	3.75
$1\frac{3}{8}$ "	4.50
$1\frac{1}{2}$ "	6.00
$1\frac{5}{8}$ "	7.50
$1\frac{3}{4}$ "	8.50
$1\frac{7}{8}$ "	10.50
2 "	11.25
$2\frac{1}{8}$ "	12.75
$2\frac{1}{4}$ "	14.00

An additional machine change-over charge of \$2.50–\$3.00 is made for each ball size.



the nearest  $\frac{1}{8}$  inch in the model, corresponding with 0.125 Å in the actual crystal for the scale here adopted, 1 inch = 2 Ångströms. All atomic positions must consequently be adjusted so as to make interatomic distances come out in integral eighth Ångströms.

In actual practice, all of the four above adjustments are carried out simultaneously. The technique of adjustment is something of an art. The attempt is made to distort the actual structure as little as possible in carrying it out. It is important to avoid serious changes in angles of interatomic bonds in this procedure, especially in structures of non-polar nature; secondarily, it is desirable to avoid important changes in radius ratios of the atomic species involved, especially in structures of ionic nature; finally, it is desirable to avoid changes in the axial ratio and cell dimensions generally.

### CALCULATION OF DRILLING COORDINATES

Before reading this section, the subject matter of which is discussed here in its correct sequence, a reader previously unfamiliar with the technique should first read the following sections on painting, drilling, and assembling in order to understand the physical requirements for the calculation of drilling coordinates.

After the adjusted structure has been completely determined, the data have to be transformed to convenient drilling coordinates. This must be borne in mind as the calculation of the structure progresses.

An atom having several packing neighbors in the structure will be represented in the model by a ball having the same number of holes. Any one of these holes may be taken as the initial hole but it is convenient to choose this origin in a position of high symmetry. This is equivalent to choosing "normal coordinates" in any analytic problem: it simplifies the entire calculating, drilling, and assembling procedure.

Ordinarily one aims to choose the origin so that in drilling there will result the smallest number of settings, in particular the smallest number of  $\rho$  settings, even at the expense of a greater number of total settings. For example, the construction of a body-centered cubic packing model requires the drilling of eight holes in each ball to represent the cubic (eight-fold) coordination of each ball. Any one of these holes could be chosen as the origin, and the subsequent drilling would require two  $\rho$  settings with three holes each, and one other  $\rho$  setting with one hole, making a total of eight holes. It is much simpler, however, to drill *nine* holes in this case: an origin hole, taken pointing along the [001] axis, and eight holes pointing along [111] axis, made with two  $\rho$  settings having four holes each. The initial hole is not used for bonding in this case;

it simply affords a convenient hold for the ball to utilize the most convenient drilling coordinates. This feature is illustrated in the sulvanite calculation given beyond.

#### PAINTING

The writers have found that the best and quickest painting procedure is as follows:

*Drilling first hole.* In order to paint a ball it is necessary to provide some means by which the ball may be grasped and handled. This is accomplished by drilling an initial hole in the ball and inserting a matchstick, the head of which has been removed. All holes are made with a  $\frac{1}{8}$  inch drill, and drilled exactly  $\frac{3}{8}$  inch deep, except in balls  $\frac{3}{4}$  inch in diameter or smaller.

The wooden balls as received from the manufacturer are slightly elliptical. Inconvenience and distortion of models may result unless the effects of this ellipticity are minimized by drilling the first hole in the direction of the axis of the rotation ellipsoid. This hole is taken as the origin to which subsequently drilled holes are referred. The axis of a ball is readily ascertained by the flattening at the poles and the concentric striations which were formed during the manufacture.

*Priming coat.* As indicated above, the balls are handled by means of matchstick inserts. The balls are mounted in racks by sticking their matchsticks into rows of holes drilled in wooden boards. The priming coat is applied to many balls at once by inverting these racks and dipping the appended balls into a bath of the priming material or agent. Raw shellac, mixed with an equal volume of methyl alcohol, constitutes a cheap and efficient agent. A narrow sheet copper trough makes a suitable container for the bath.

*Non-metallic finish.* After the priming coat on the balls has dried, they are dipped individually<sup>9</sup> in Duco of the desired color. After dipping, the matchstick handle of a ball is replaced in the rack and the ball allowed to dry. This technique gives a durable, smooth, glossy finish to each ball. An advantage is the presence of a slight puckering in the paint which occurs around the matchstick while the ball is drying. This serves to distinguish the initial origin-of-coordinates hole from other holes, a great convenience when assembling the model.

*Metallic finish.* Metallic elements have been successfully represented by gilding balls with metallic powders suspended in lacquer. After the priming coat, the balls are individually dipped into a suspension of Sapolin metallic gilding powder (Sapolin Co., Inc., New York) in Rogers clear brushing lacquer (Detroit White Lead Works, Detroit, Mich.).

<sup>9</sup> Spraying by means of a paint gun has been tried but found to be unsatisfactory; the finish is uneven and much paint is wasted.



The proportions of the proper mixture seem to vary slightly from time to time. About 0.5 oz. of copper powder or 15 c.c. of aluminum powder to 100 c.c. of lacquer provide a mixture which does not have to be greatly diluted or thickened to attain the desired consistency. Mechanical agitation is required to mix the materials evenly. The writers have used the following metallic powders: copper, aluminum, and brass. Bronze and gold powders are also available.

### DRILLING

Drilling of the appropriate holes in the balls is accomplished on the machine illustrated in figure 1. It has been described in detail elsewhere.<sup>10</sup>



FIG. 1. Ball orienting device attached to drill press.

The device has been designed so as to drill any possible holes which are necessary to bond the individual ball to its neighbors in the completed model. The coordinates for the holes are expressed in  $\rho$  and  $\phi$  angles, where  $\rho$  is the co-latitude and  $\phi$  the longitude. Thus, the first hole, which has already been drilled and into which the matchstick handle was inserted in the painting procedure, has for coordinates  $\rho=0$ ,  $\phi=0$ . Any hole on the equator of a ball has the co-latitude co-

<sup>10</sup> Buerger, M. J., A device for drilling oriented holes in spheres required in the construction of crystal structure models: *Rev. Sci. Inst.*, Vol. 6, pp. 412-416, 1935.

ordinate,  $\rho = 90^\circ$ . A steel orienting rod is inserted in the initial hole of the ball about to be drilled, and this is then attached to the instrument through a hollow shaft to which it is clamped.

The dial attached to the hollow shaft indicates the meridian angle,  $\phi$ . The entire  $\phi$  assembly slides in a grooved track in the  $\rho$  arc to which it may be clamped at any desired  $\rho$  setting. In figure 1, the  $\rho$  angle setting is about  $60^\circ$ .

The procedure for drilling a hole consists of setting the  $\rho$  angle on the vertical arc, turning to the correct  $\phi$  angle on the dial, clamping the ball tightly, and then drilling the hole. The clamp is always completely opened when settings are changed.

In any machine of this type clamping may introduce a slight rotation of a ball in its seat about the orienting rod axis. This presents a serious error. The rotation can be easily detected by the change in reading of the  $\phi$  dial which is free to rotate with any movement of the ball. When this error occurs, the clamp should be opened, the  $\phi$  dial reset, and the clamp again tightened.

After all required holes are drilled in a ball, the rod is unclamped from the hollow shaft and the ball removed. An experienced operator can drill between 15 and 40 balls per hour, depending, of course, on the number of individual settings involved.

#### ASSEMBLING

*Rinning.* The models are assembled by bonding the drilled balls to one another by means of short brass pins. Eighth-inch brass rod stock is clipped into pins  $\frac{5}{8}$  inch long. Clipping burrs, present on the ends of the pins, are easily removed by rotating the pin held in a special clamp, against a small emery wheel.

Layer types of structures, of which molybdenite is an example, consist of discreet sheets of atoms. Atoms within the same sheet pack normally, but the nearest atoms of neighboring sheets are separated by greater than packing distances. To bond these separated sheets in the representation of the actual structure, pins are used which have been cut to the length required to separate the atoms by the appropriate spacing as shown in figure 2. Models of such layer structures are packing models in every sense, the packed sheets being held apart at their actual scale non-packing distance by the brass rods.

Omission of outside holes in the outer balls of a model, because no further bonding is necessary in this direction, involves greater difficulty in the end in the way of calculation, orientation, and assembly than is required to drill *all* holes, whether used or not. Furthermore, the presence of outside holes on the finished model allows it to be extended,



should the need arise. These outside holes also indicate the positions of neighboring atoms in the extended structure.

*Orientation.* The orientation of the ball with respect to its normal coordinates can be recognized by picking out the ellipsoid axis by means of the puckered ring of paint around the first hole, together with the arrangement of holes about this axis. In cases of close correspondence of the actual, distorted coordination environment with an ideal one (octahedral, for example), the orientation may be recognized by plugging all holes with long brass pins.

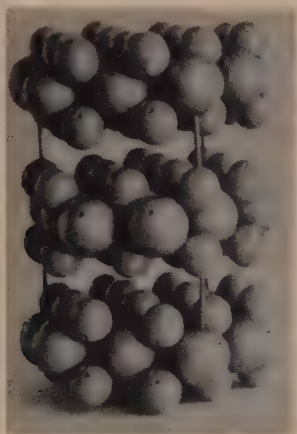


FIG. 2. Model of a layer structure: molybdenite. Large balls represent molybdenum atoms, small balls, sulfur atoms. The structure displays normal packing within sheets, but there is no packing between the atoms of adjacent sheets. In the model, the sheet spacing is maintained by occasional spacing rods of appropriate length.

In general, it is necessary to orient a ball in the structure so that the axes and drilling array of equivalent balls are related by space group symmetry operations.<sup>11</sup> This requires the axes of equivalent balls to be related by these symmetry operations. In some cases, however, simpler drilling and assembling may be attained by purposely disregarding space group symmetry with respect to the ball axes, and arranging to have all ball axes point the same way. For example, in the diamond structure, the balls ought to have tetrahedral symmetry; actually they have an approximately cylindrical symmetry. The diamond structure and certain derived structures are accordingly best built by taking

<sup>11</sup> In this connection the reader should reread the last part of the section entitled, CALCULATION OF THE ATOMIC ENVIRONMENT IN THE ACTUAL CRYSTAL, with particular regard to the possibility of atoms being related by having right- and left-handed environments.

the ball axis as either the crystallographic [001] axis or the crystallographic [111] axis, and orienting *all* balls along either one or the other of these two axes. This gives the resulting structure a slight dimensional distortion of tetragonal or hexagonal symmetry, respectively, because of the slightly elliptical nature of the balls, but gives a well-fitted model.

*Methods.* Models are assembled by pegging the holes in the balls with the brass pins and uniting balls to their proper neighbors. Various difficulties are likely to be encountered in the very close-packed structures. These are minimized by omitting brass pins in certain holes. This omission, if appropriately practiced, does not weaken the model.

Most favorable assembly conditions are realized in models assembled in sheets which can be pegged together. The construction of the sheets is easiest if they can be made up of strings which can be pegged together. Worst construction conditions occur if the structure does not permit sheet-like assemblage, but requires balls or units to be placed into the structure as individuals.

Each separate structure presents a distinct problem in calculation, adjustment, drilling, orientation, and assembling which, when correctly carried out, may be made to yield an excellent model.

#### EXAMPLES OF CALCULATIONS

##### INTRODUCTION

In the foregoing section, the calculations required for the construction of crystal models have been discussed in very general terms. In order to illustrate the application of some of the more important principles discussed, examples of calculations for two structures, marcasite and sulvanite, are included in the present section. Marcasite provides an illustration in which very little adjustment is necessary for the construction of an appropriate model, while sulvanite illustrates the adjustments necessary when three different atomic species of dimensions incompatible with available ball sizes, must be fitted into a structure.

##### MARCASITE STRUCTURE

*Introduction.* The data necessary for the construction of a model of the marcasite structure are found in the original article<sup>12</sup> which should be consulted in connection with the following calculations. These include the following information:

Unit cell:  $a = 3.37 \text{ \AA}$   
 $b = 4.44 \text{ \AA}$   
 $c = 5.39 \text{ \AA}$

<sup>12</sup> Buerger, M. J., The crystal structure of marcasite: *Am. Mineral.*, vol. 16, pp. 361-395, 1931.



Space group:  $V_h^{12}$

Iron atoms (on symmetry centers) at:  $[[000]]$  and  $[[\frac{1}{2}\frac{1}{2}\frac{1}{2}]]$

Sulfur atoms (on reflection planes) at:  $[[0u_b\bar{v}_c]]$ ,  $[[0\bar{u}_b v_c]]$ ,

$$[[\frac{1}{2}, \frac{1}{2} - u_b, \frac{1}{2} + v_c]], \text{ and } [[\frac{1}{2}, \frac{1}{2} + u_b, \frac{1}{2} - v_c]]$$

where

$$u_b = .203 + .01$$

$$v_c = .375 + .01$$

(Conventional marcasite orientation, origin at a symmetry center.)

Paired sulfur distances      2.25 Å

Sulfur-iron distances      2.21 Å and 2.24 Å

It will be observed that the sulfur-iron distances actually found for marcasite are of two kinds which are almost, but not quite identical, namely 2.21 Å and 2.24 Å. Since it is physically impossible to pack spheres in contact so that there will be two non-identical central distances between spheres of two kinds, after this fashion, it is necessary to adjust the structure so that all iron-sulfur packing distances are equal.

*Choice of ball sizes.* The appropriate ball sizes are selected as follows: The paired sulfur distance is 2.25 Å. From this it follows that the sulfur radius is half this, or 1.125 Å. The sulfur atom can therefore be represented exactly by a ball  $1\frac{1}{8}$  inches in diameter on the scale adopted (1 inch = 2 Ångstroms). By subtracting the actual sulfur radius, 1.125 Å, from the sum of the iron and sulfur radii, one arrives at two apparent iron radii, depending on which sulfur-iron distance is used:

$$\text{Fe} + \text{S} = 2.21 \text{ Å and } 2.24 \text{ Å}$$

$$\text{S} = 1.125 \quad \text{and} \quad 1.125$$

---


$$\text{Fe} = 1.085 \text{ Å and } 1.115 \text{ Å}$$

The available ball diameters in this region represent radii of 1.000 Å and 1.125 Å, respectively. Obviously, the iron atom is best represented by a ball of  $1\frac{1}{8}$  inches diameter.

*Adjustment to packing requirements.* The actual marcasite structure must now be slightly distorted so that it appears to be composed of sulfur atoms 1.125 Å in radius and iron atoms 1.125 Å in radius, with a paired sulfur distance of 2.25 Å and a closest iron-sulfur distance of 2.25 Å. This can be accomplished in many different ways. The situation can be grasped from figures 3*a* and 3*b*, the notation of which is the same as in the illustration in the original article. The distances *AO* and *AD* must be reduced to equality with *BA*, which is already correctly 1.125 inches. Two simple ways are open to accomplish this:

- (1) Alter the sulfur parameters until  $AO$  is 1.125 inches, keeping the sulfur-sulfur spacing constant; then respace the (100) sheets until the iron-sulfur spacing  $AD$  equals 1.125 inches.
- (2) Leave the sulfur atoms untouched, increasing the cell height slightly until the iron-sulfur spacing,  $AO$ , equals 1.125 inches; then respace the (100) sheets until the iron-sulfur spacing  $AD$  equals 1.125 inches.

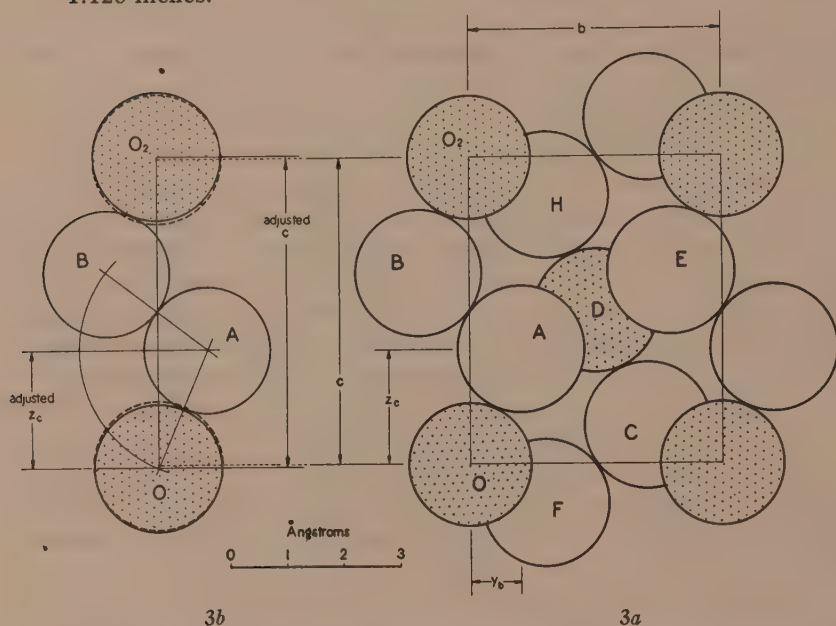


FIG. 3. Projection of the marcasite structure on (100). 3a. Projection of the actual structure. 3b. Graphical adjustment of the structure to the requirements of commercially available balls.

The second alternative is arbitrarily adopted here, and illustrated in figure 3b.

The adjustment is readily accomplished graphically as shown in the illustration.  $AB \wedge (001)$ ,  $36.9^\circ$  (determined from the cosine relation of  $y_b$  and  $AB/2$ ) has been laid off at  $[[00\frac{1}{2}]]$  on the scale projection of part of the (100) plane. The dotted horizontal lines on the projection represent the traces of (001) planes which limit the  $c$ -axis length of the actual cell.

If spheres 1.125 Å in radius are used to represent Fe atoms (dotted circles), the overlap represents the obvious misfit in this actual cell. The correct packing condition is given by the full circles which determines the adjusted cell height indicated by the full lines.



On the scale projection the equality,  $AB=AO$ , is realized graphically by describing an arc using  $A$  as a center and  $AB$  as radius. The adjusted position of  $O$  is indicated by the full-lined circle. The distance separating the nearly coincident dotted and full circles is one-half the  $c$ -axis adjustment. The net results of this adjustment are a slight change in the length of the  $c$ -axis of the unit cell, and consequent changes in the  $z_c$  parameter and dependent angles.

Revised data to this point are as follows:

New  $c$ -axis length = 5.52 Å (graphically)

$$\text{New } z_c = \text{original } z_c + \frac{\text{new } c - \text{original } c}{2} = 2.08 \text{ Å}$$

$$\text{New } v_c = \frac{2.08}{5.52} = .377.$$

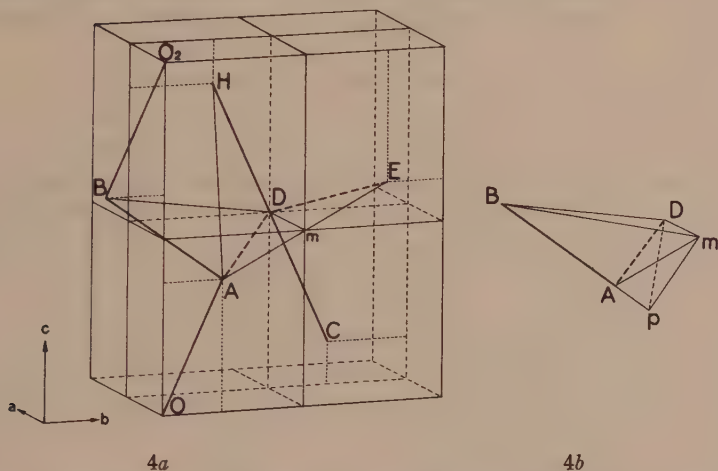


FIG. 4. Some geometrical aspects of the marcasite crystal structure useful in the derivation of adjusted structure data and in the calculation of drilling coordinates.

The clinographic projection, figure 4a, has been constructed to show the essential coordination of an Fe atom,  $D$ , and a sulfur atom,  $A$ . The entire unit cell is outlined, but only the positions of certain atoms in two adjacent (100) planes are indicated.

Heavy full lines in the projection represent bondings within (100) planes; heavy dashed lines, the bondings between adjacent (100) planes; and the lighter lines indicate the unit cell, certain triangles useful in the computation, and parameters which fix atomic positions. Capitalized block letters denote atoms, and small letters, points useful in the computations.

For subsequent computations, the length of the  $a$ -axis of the structure when using the requisite ball diameters is necessary. This adjustment fits together the adjacent (100) planes. The interatomic distance,  $DA$ , of the actual structure is  $2.24 \text{ \AA}$ , and the distance in the model must correspond to  $2.25 \text{ \AA}$ , thus requiring a change in the distance  $Dm$ . The length of the  $b$ -axis and the positions of the two sulfur atoms,  $A$  and  $E$ , are not altered in this type of adjustment. Right triangle,  $ADm$ , is readily solved by the relation,

$$Dm = \sqrt{(AD)^2 - \left(\frac{AE}{2}\right)^2} = 1.694 \text{ \AA}.$$

The increase in  $a/2$  is  $0.009 \text{ \AA}$ .

These calculations provide a slightly idealized marcasite structure composed of spheres in packing contact. This revision of cell constants constitutes a necessary preliminary to the calculation of drilling coordinates.

*Calculation of Drilling Coordinates.* As stated before, the most convenient origin of coordinates (initial hole of ball) is chosen with due regard to the space group symmetry and such that the easiest drilling coordinates will be realized. In the marcasite structure, the origin of coordinates for both Fe and S has been chosen in the (100) plane. Fe atom,  $D$ , has six S atoms grouped about it. The most convenient origin of coordinates about  $D$  is in the direction  $D \rightarrow H$ . Similarly,  $A \rightarrow B$  is selected as the direction of origin of coordinates about S atom,  $A$ .

The  $\angle BAO$  can be determined graphically from figure 3b as  $103.5^\circ$ . This is one of the necessary  $\rho$  angles for the drilling of S atom,  $A$ . In order to obtain the value of the other  $\rho$  angle for the S atom,  $\angle BAD$ , triangle  $BAD$  must be solved. Triangle  $BAD$  is isosceles as a result of previous adjustment to ball sizes.

$$BA = AD = 2.25 \text{ \AA}$$

$$B = [[0, -y_b, 1 - z_c]]$$

$$D = \left[\left[\frac{1}{2}, \frac{1}{2}, \frac{1}{2}\right]\right].$$

According to the relation given on page 152,

$$BD = \sqrt{\left(\frac{a}{2} - 0\right)^2 + \left(\frac{b}{2} - [-y_b]\right)^2 + \left(\frac{c}{2} - [c - z_c]\right)^2} = 3.61 \text{ \AA}.$$

$$\sin \angle \frac{BAD}{2} = \frac{\frac{1}{2}(BD)}{AD}, \text{ whence } \angle \frac{BAD}{2} = 53.3^\circ$$

$$\angle BAD = 106.6^\circ.$$



Solution of triangle  $HDA$  for  $HDA$ , a necessary angle of Fe, is similar to the solution of triangle  $BAD$ .

$$AD = DH = 2.25 \text{ \AA}$$

$$A = [[0, y_b, z_c]]$$

$$H = [[\frac{1}{2}, \frac{1}{2} - y_b, \frac{1}{2} + z_c]]$$

$$AH = \sqrt{\left(\frac{a}{2} - 0\right)^2 + \left(\left[\frac{b}{2} y_b\right] - y_b\right)^2 + \left(\left[\frac{1}{2} + z_c\right] - z_c\right)^2} = 3.16 \text{ \AA}.$$

$$\sin \angle \frac{HDA}{2} = \frac{\frac{1}{2}(AH)}{HD}, \text{ whence } \angle \frac{HDA}{2} = 44.6^\circ$$

$$\angle HDA = 89.2^\circ.$$

Figure 4b illustrates the relation between bond angles and  $\phi$  angles. Half the bond angle,  $DAm$ , projects on a plane normal to the origin direction,  $AB$ , to give a  $\phi$ -angle,  $Dpm$ , of the ball  $A$ .

$$\angle DAp = 180^\circ - \angle BAD = 73.4^\circ$$

$$\sin 73.4^\circ = pD/DA, \text{ whence } pD = 2.16 \text{ \AA}$$

$$\sin \angle Dpm = Dm/Dp = \frac{a/2}{Dp}, \text{ whence } \angle Dpm = 51.3^\circ.$$

Ordinarily, the calculation of the  $\phi$  angle for the drilling of the iron atom,  $D$ , would be carried out in a manner analogous to the calculation of the  $\phi$  angle for drilling of the sulfur atom,  $A$ , just discussed. The fortuitous position of the plane containing the atoms  $A$ ,  $D$ , and  $E$ , however, at a deviation of only  $0.8^\circ$  from normality with the origin direction,  $DH$ , renders the  $\phi$  angle substantially equivalent to the bond angle  $\angle ADE$ , and simplifies calculations. In this case, therefore, solution of triangle  $ADE$  will give the  $\phi$  angle of Fe atom,  $D$ .  $\angle ADE/2 = \angle ADm$  is desired.

$$AD = DE = 2.25 \text{ \AA}$$

$$AE = 2.96 \text{ \AA (original paper)}$$

$$\sin \angle ADm = \frac{AE/2}{AD}, \text{ whence } \angle ADm = 41.1^\circ.$$

*Derivation of Drilling Coordinates.* In the previous section, angles necessary for the derivation of the drilling coordinates,  $\rho$ , the co-latitude, and  $\phi$ , the longitude, have been calculated. Appropriate choice of ball orientation with regard to the symmetry of the positions of the atoms leads to a minimum amount of further calculation.

Consideration of figures 4 and 5 illustrates the application of symmetry to derivation of drilling coordinates. Figure 5 shows the elevation and plan of the drilling environments of S atom,  $A$ , and Fe atom,

*D.* Projection points,  $p$  and  $m$ , are diagrammatically indicated. The Fe atom, *D*, has a center of symmetry; the S atom, *A*, does not possess one. In each case, the position of the symmetry plane, (001), is indicated on the plan view.

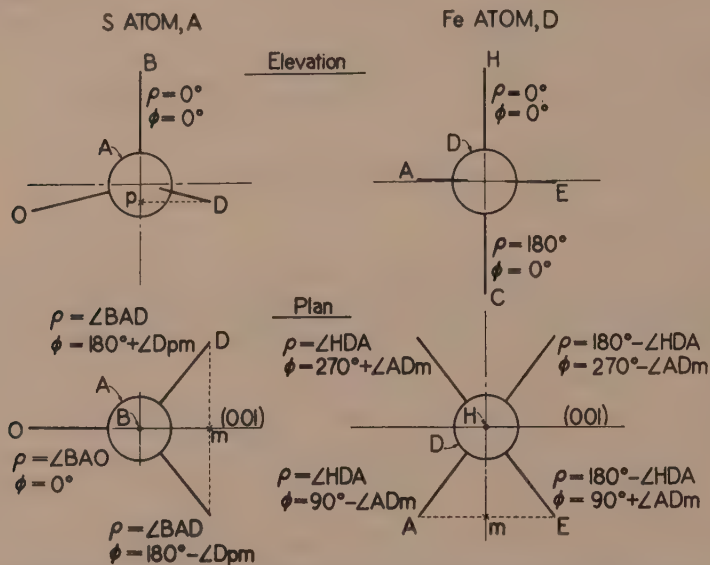


FIG. 5. Plans and elevations of balls representing sulfur and iron atoms in the model of the marcasite structure, showing drilling coordinates.

Since the origin of coordinates of S atom, *A*, has been chosen in the direction,  $A \rightarrow B$ , and atom *O* is located on the symmetry plane which is chosen in the direction  $\phi = 0^\circ$  and  $\phi = 180^\circ$ , the determination of  $\angle BAO$  locates the hole to be drilled in *A* which will bond it to atom *O*. The machine in use (figure 1) requires drilling coordinates to increase in longitude angles in a counterclockwise direction. Drilling of the hole for the bond,  $A \rightarrow D$ , has been located by  $\rho$  angle  $BAD$ , and  $\phi$  angle  $Dpm$  which is referred to the  $A \rightarrow O$  direction in the (001) plane. Coordinates of the remaining hole to be drilled in the S atom are immediately apparent from the symmetry.

The centro-symmetrical aspect of the environment of the Fe atom, *D*, plus the presence of the symmetry plane permit the coordinates of one bond to be established with reference to an origin, from which the drilling coordinates of the others may be immediately derived from symmetry. Thus,  $\rho$  angle  $HDA$ , and the complement of  $\phi$  angle  $ADm$  locate the drilling coordinates of the hole,  $D \rightarrow A$  of atom *D*, with reference to  $D \rightarrow H$  as the initial hole, and to the symmetry plane (001) as the direction,  $\phi = 0^\circ$  and  $\phi = 180^\circ$ . The coordinates for the reflection equivalent of



atom *A* are easily derived by symmetry, from which the coordinates for bonds to the atoms of the centro-symmetrical pair may be determined. The coordinates to atom *C* are obviously  $\rho=180^\circ$ ,  $\phi=0^\circ$  as *D*→*H* is the initial hole.

Drilling coordinates for the marcasite model are given in Table 1.

TABLE 1  
DRILLING COORDINATES FOR BALLS USED IN MARCASITE  
CRYSTAL STRUCTURE MODEL

Atom	Bond to	Drilling Coordinates	
		$\rho$	$\phi$
S	Fe	0	0
	Fe	$\angle BAO=103.5^\circ$	0
	Fe	$\angle BAD=106.6^\circ$	$180^\circ - \angle D\phi m = 128.7^\circ$
	Fe	$\angle BAD=106.6^\circ$	$180^\circ + \angle D\phi m = 231.3^\circ$
Fe	S	0	0
	S	$\angle HDA = 89.2^\circ$	$90^\circ - \angle ADm = 49^\circ$
	S	$\angle HDA = 89.2^\circ$	$270^\circ + \angle ADm = 311^\circ$
	S	$180^\circ - \angle HDA = 90.8^\circ$	$90^\circ + \angle ADm = 131^\circ$
	S	$180^\circ - \angle HDA = 90.8^\circ$	$270^\circ - \angle ADm = 129^\circ$
	S	$180^\circ$	0

A photograph of the completed model of marcasite is shown in figure 6.



FIG. 6. Model of the crystal structure of marcasite constructed in accordance with the procedure outlined in the accompanying text. The model contains eight unit cells plus some bordering sulfur atoms necessary to complete the sulfur pairs.

## SULVANITE STRUCTURE

*Introduction.* The data needed to calculate the coordinates for a model of the sulvanite structure are found in the original article.<sup>13</sup> These include the following:

Unit cell:  $a_0 = 5.37 \text{ \AA}$

Contains 1  $\text{Cu}_3\text{VS}_4$

Space group:  $T_d^1 - P\bar{4}3m$

Atomic arrangement:

V at  $[[000]]$

3 Cu at  $[[\frac{1}{2}00]]$ ,  $[[0\frac{1}{2}0]]$ ,  $[[00\frac{1}{2}]]$

4 S at  $[[uuu]]$ ,  $[[u\bar{u}\bar{u}]]$ ,  $[[\bar{u}u\bar{u}]]$ ,  $[[\bar{u}\bar{u}u]]$ .

where  $u = 0.235$

Coordination distances:

Cu: S = 2.285  $\text{\AA}$

S: S = 2.186  $\text{\AA}$

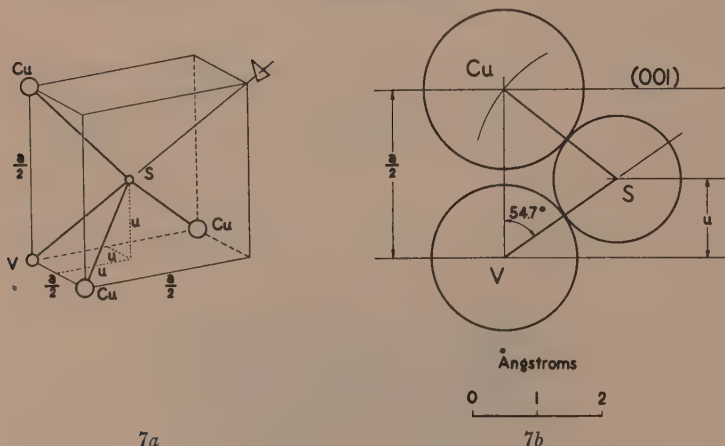


FIG. 7. Some geometrical features of the sulvanite structure.

7a. Positive octant of the structure containing the origin (at V).

7b. (110) plane through the origin of 7a, illustrating the adjustment of the structure to the packing requirements of commercially available balls.

The diagram in the original article gives an excellent idea of the structure. Some of its essential characteristics necessary for the present purposes are illustrated in figure 7a which shows one octant of a unit cell. The metals occupy special positions at certain corners while the S is located along the trigonal axis, its position being defined by the parameter  $u$ .

<sup>13</sup> Pauling, Linus and Hultgren, Ralph, The crystal structure of sulvanite,  $\text{Cu}_3\text{VS}_4$ : *Zeit. Krist.*, vol. 84, pp. 204-212, 1933.

*Choice of ball sizes.* The packing conditions can be best studied in the (110) plane through the origin; this contains all three atoms. Figure 7*b* illustrates this. It will be observed that with the V, Cu, and S positions as shown it is possible to have various coordination effects depending on the relative atomic sizes. Thus, if the S is small it would be possible for the V and Cu atoms to be in contact. In order to get some notion of the packing, the normal radii of Cu, S, and V in tetrahedral and other non-polar structures<sup>14,15</sup> may be tested. These radii are as follows:

$$\text{Cu} = 1.35 \text{ \AA}$$

$$\text{S} = 1.04 \text{ \AA}$$

$$\text{V} = 1.32 \text{ \AA}$$

These radii prove to be definitely inconsistent with the sulvanite structure as given. The sum of the expected V and S radii, 2.36 Å, is considerably in excess of the V:S distance, 2.186 Å, given by Pauling and Hultgren. If the S parameter were approximately .25 instead of .235 as given, the V and S would not only pack perfectly with the expected radii, but the Cu atoms would also be surrounded by an ideally tetrahedral S environment which is not the case in Pauling and Hultgren's structure. The object of the present discussion, however, is to lead to a model of the sulvanite structure substantially identical with the one described in the original article. In selecting atomic dimensions for the structure, the following actual radius relations are important:

$$\text{Cu} + \text{S} = 2.285 \text{ \AA}$$

$$\text{V} + \text{S} = 2.186 \text{ \AA}$$

$$\text{Cu} - \text{V} = 0.099 \text{ \AA}$$

This indicates that whatever ball sizes are chosen to represent the Cu and V atoms, the radius of the Cu atom should exceed the radius of the V atom by 0.099 Å. The best approximation possible with the ball sizes available is to have the Cu and V balls differ in diameter by 0.125 inch.

This condition gives no clue to the absolute atomic radii necessary to represent the structure. If, however, the radius of any one atom is decided upon, the radii of the other two follow from the geometry of the positions of the three atoms, figure 7*b*, together with the condition noted above. Taking the radius of the S atom as the standard non-polar sulfur radius 1.04 Å the atomic radii become:

<sup>14</sup> Pauling, Linus and Huggins, M. L., Covalent radii of atoms and interatomic distances in crystals containing electron-pair bonds: *Zeit. Krist.*, vol. 87, p. 218, 1934.

<sup>15</sup> *Ref. 4*, pp. 192-193.



$$\begin{aligned} S &= 1.04 \text{ \AA} \\ \text{Cu} &= 2.285 - 1.04 = 1.245 \text{ \AA} \\ \text{V} &= 2.186 - 1.04 = 1.146 \text{ \AA}. \end{aligned}$$

Adopting the standard scale of 1 in. = 2 Å, the available ball diameters best approximating these atomic sizes are as follows:

$$\begin{aligned} S \quad 1.00 \text{ inch diameter} &= 1.00 \text{ \AA radius} \\ \text{Cu} \quad 1.25 \text{ inches diameter} &= 1.25 \text{ \AA radius} \\ \text{V} \quad 1.125 \text{ inches diameter} &= 1.125 \text{ \AA radius} \end{aligned}$$

*Adjustment to packing requirements.* The necessary adjustment of these ball sizes to the structure may be conveniently and simply carried out by graphical means as illustrated in figure 7b. Half the tetrahedral angle, angle Cu—V—S = 54.7°, is laid off in a (110) plane. The S position is located in this direction at the adjusted V:S interatomic distance, 2.125 Å. The intersection of the *a*-axis with an arc of radius equal to the adjusted Cu+S interatomic distance, 2.25 Å, centered at the adjusted S position, fixes the adjusted Cu position satisfying packing requirements. Revised cell data are:

$$\begin{aligned} a &= 5.35 \text{ \AA} \\ u &= .234 \end{aligned}$$

*Calculation of drilling coordinates.* The origin of coordinates of V may be chosen either in the direction V→S or V→Cu. By choosing V→Cu as the origin direction, the  $\rho$  angle for V is the angle Cu—V—S = 54.7° of figure 7b, and may be read from the figure. This choice eliminates the effects of irregularities in the balls. The  $\phi$  angles are fixed by the space group symmetry at 90° intervals.

Choosing the direction Cu→V as the origin direction of Cu, the requisite  $\rho$  angle, V—Cu—S, may be read from figure 7b as 49.8°. This origin direction eliminates effects of ball irregularities as well as calculation of  $\phi$  angles, which are fixed by space group symmetry at 90° intervals.

The most convenient drilling coordinates for the S atom are referred to the trigonal symmetry axis, S→V, as origin direction with  $\phi$  angles at 120° intervals. The  $\rho$  angle for S, angle V—S—Cu, is graphically determined from figure 7b as 75.5°.

*Derivation of drilling coordinates.* It has been indicated in the foregoing section that the directions of origin of coordinates for both V and Cu are in directions in which there is no neighboring atom in packing contact; the initial holes, therefore, are not bonded in the completed

model. These holes are useful only for manipulation. The origin hole of S, however, is bonded to V in the model.

With reference to figures 7*a* and 7*b*, the direction of origin of  $\rho$  angles has been noted, and the most convenient reference direction of  $\phi$  angles for all atoms is in a (110) plane. The completed derivation of all angles is given in Table 2, showing the bond for which each hole is intended.

TABLE 2

DRILLING COORDINATES FOR BALLS USED IN THE SULFANITE CRYSTAL STRUCTURE

Atom	Bond to	Drilling coordinates	
		$\rho$	$\phi$
V	S	54.7°	0°
	S	54.7°	180°
	S	180°-54.7°=125.3°	90°
	S	180°-54.7°=125.3°	270°
Cu	S	49.8°	0°
	S	49.8°	180°
	S	180°-49.8°=130.2°	90°
	S	180°-49.8°=130.2°	270°
S	V	0°	0°
	Cu	75.5°	0°
	Cu	75.5°	120°
	Cu	75.5°	240°

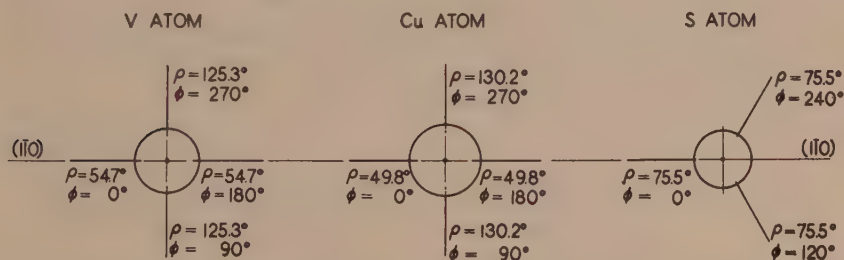


FIG. 8. Plans of balls representing copper, vanadium, and sulfur atoms in the model of the sylvanite structure, showing drilling coordinates.

Diagrammatic representation is shown in figure 8, where the drilling coordinates are projected onto a plane perpendicular to the origin direction of each atom.

Figure 9 illustrates the complete sulvanite model.

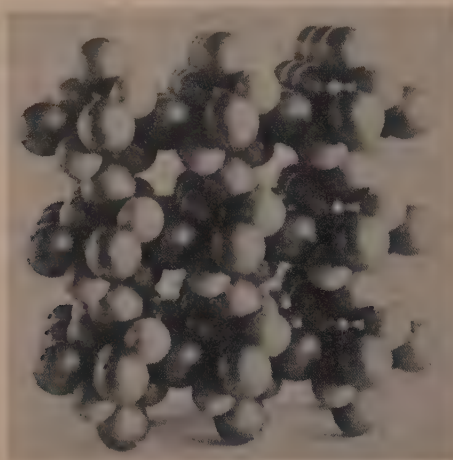


FIG. 9. Model of the crystal structure of sulvanite constructed in accordance with the procedure outlined in the accompanying text. The octahedron-like clusters contain copper atoms at the octahedron corners, sulphur atoms near the centers of alternate octahedron faces, and vanadium atoms at the octahedron centers. The model contains eight unit cells plus additional atoms necessary to complete the environments of the vanadium atoms.

#### COLLECTED DRILLING COORDINATES

During the past few years the writers have had occasion to construct packing models of some forty odd crystal structures. A considerable amount of labor has been expended in the adjustment of the structures and in the calculation of drilling coordinates. These drilling coordinates will be published in a subsequent paper for the benefit of those wishing to duplicate these structural models.



## MEMORIAL OF EDWARD SALISBURY DANA

WILLIAM E. FORD, *Yale University, New Haven, Conn.*

Edward Salisbury Dana, the Dean of American mineralogists, died on June sixteenth, 1935, at his home in New Haven. In order to appreciate properly his position and influence one must consider briefly the history of his family. The following dates are significant ones, not only in the family records, but in the annals of American science.



EDWARD S. DANA  
1849-1935

### BENJAMIN SILLIMAN

Born August 8, 1779.

Graduated from Yale in 1796.

Appointed Professor of Chemistry and Natural History at Yale in 1804.

Founded the *American Journal of Science* in 1818.

Died November 24, 1864, aged 85.

### JAMES DWIGHT DANA

Born February 12, 1813.

Graduated from Yale in 1833.

Appointed Assistant in Chemistry at Yale in 1836.

Published *System of Mineralogy* in 1837.

Married Henrietta Frances Silliman, June 5, 1844.

Became an Editor of *American Journal of Science* in 1846.

Died April 14, 1895, aged 82.

## EDWARD SALISBURY DANA

Born November 16, 1849.

Graduated from Yale in 1870.

Became an Editor of *American Journal of Science* in 1875.

Published *Textbook of Mineralogy* in 1877.

Published Sixth Edition, *System of Mineralogy* in 1892.

Died June 16, 1935, aged 85.

The above is without doubt a unique family record. For more than one hundred years these three men, grandfather, son and grandson, were leaders in American science, not only by their own contributions, but even more through their books and the Journal which they established and maintained. It is not necessary to enlarge upon these facts; the bare record is sufficiently eloquent.

It was natural that Edward Dana should on graduation from Yale turn his attention to science and in particular to mineralogy. He studied for two years under Professor George J. Brush of the Sheffield Scientific School and then went abroad where he worked for two years at Heidelberg and Vienna. At the latter place he studied with Tschermak, Lang and Schrauf. His stay there must have a most fruitful and pleasant one. He learned the methods of investigation in crystallography and crystal optics, fields in which most of his original investigations were to lie. He also made many friendships which were to endure through the years and which led him to help in the relief of the impoverished Vienna scientists in the dark years after the war. Many members of the Mineralogical Society of America answered Dana's appeals and know personally how he conducted this friendly work. It seems appropriate to record here in part the greeting sent to Dana by the Vienna Academy on his eightieth birthday.

"We recognize you as the master and leader of American mineralogists and we of Vienna may rightfully claim Edward S. Dana as one of ourselves. Since 1873 bonds of personal friendship have been formed between you and a number of physicists and mineralogists in Vienna. . . . With this circle of friends you have kept faith during one of the saddest times which Vienna and Austria have ever experienced. . . . We all think of you with lasting gratitude."

After his stay abroad Dana came back to New Haven and his work at Yale. He took there the M.A. degree in 1874 and the Ph.D. degree in 1876. While his teaching at Yale was largely in physics, at which he was most successful, his scientific investigations and writings were almost entirely concerned with mineralogy. His bibliography is a long one and cannot be given here but will be published shortly in the *Transactions of the Geological Society of America*. A few comments, however,

should be made upon it. He published in 1872 the first paper in America to deal with the investigation of a rock from the petrographic point of view. His doctor's thesis was on "The Trap Rocks of the Connecticut Valley" and was the first important petrographic memoir to be published here. The record shows that he published the results of investigations on a total of at least fifty-five different mineral species. In the sixth edition of the *System of Mineralogy* the crystallographic axial ratios of the following twenty species are credited to him; beryllonite, chondrodite, columbite, danburite, dickinsonite, eosphorite, fairfieldite, fillowite, herderite, hureaulite, monazite, pectolite, polianite, reddingite, samarskite, stibnite, triploidite, tyrolite, tysonite and willemite. He was in part responsible for the description of ten new species, namely dickinsonite, durdenite, eosphorite, eucryptite, fairfieldite, fillowite, lithiophilite, natrophilite, reddingite and triploidite.

From the above one can see that Dana's research was varied and of no inconsiderable amount. It was, however, through his books that he made his greatest contribution to mineralogical science. His first volume, which was published in 1877, was the *Textbook of Mineralogy*. A book of this type had been planned by his father but ill health intervened and he turned it over to Edward who was only twenty-eight when the book was published. (James Dwight Dana had published the first edition of "The System" when he was twenty-four!) The *Textbook* is still in active use, the second edition being published in 1898, the third in 1921, and the fourth in 1932.

All mineralogists will agree that Dana's greatest contribution to mineralogy and the one upon which his fame securely rests was the publication in 1892 of the sixth edition of the *System of Mineralogy*. The fifth edition had been published in 1868. There was, therefore, an interval of twenty-four years between the two editions. This period was one of active mineralogical research and a great amount of new data had accumulated during it. The sixth edition was therefore in great part a new book. Further it was in all essentials the work of one man. Dana enlisted clerical help in the recalculation of the crystal angles and in the re-drawing of the crystal figures and of course had advice and assistance from a great many mineralogists the world over, but the entire direction and a very large part of the actual work was his alone. It probably took him about ten years, but during this time he was actively engaged in college teaching and administration, and in his duties as an editor of the *American Journal of Science*. It was a very great burden that he carried in that period and it is not surprising that when it was over his health was impaired, and during the subsequent years his activities had to be much curtailed.



The sixth edition was remarkable in many ways. Its accuracy has astonished all who have used it. There were so many chances for errors and misprints and so few have ever been found. The judgment shown was so keen and well-balanced that mineralogists have frequently referred to it as the "mineralogists' bible." A study of the material included in the paragraph headed **REF.** at the end of the descriptions of species will show clearly how Dana balanced conflicting ideas and formed his conclusions concerning contradictory data. In many instances he published here the results of his own investigations which had not been printed elsewhere; two instances being the crystallographic data for pectolite and willemite. Considerable material was also supplied by other investigators in advance of publication elsewhere. Unquestionably this book, even today more than forty years after its publication, remains the most important contribution to mineralogical science that has come from America.

The *American Journal of Science* is the oldest scientific magazine in the country. Established by Silliman in 1818, the journal was edited and financially maintained by him and the two Danas until 1926, a period of one hundred and eight years. Edward Dana was its directing force for upward of forty years, and in fact continued an active interest in its affairs until his death. As an editor he made his second most important contribution to American science.

Fortunately many American mineralogists at one time or another came into personal contact with Dana. They were familiar with his great charm, his unfailing good humor, his modesty and his delight in being able to offer assistance. He was the most delightful and entertaining companion, full of a quiet humor and ready with an appropriate story or reminiscence. Until very recently he was physically vigorous and delighted in long walks and climbs both about New Haven and among the hills of Mount Desert Island where he had his summer home. For years he was accustomed to ride about the streets of New Haven on a bicycle, and only relinquished the habit when his family protested that his age and the increase in motor traffic made the practice too dangerous. He probably owned an overcoat but the present writer cannot recall ever having seen him wear one. His only concession to winter weather was the occasional wearing of a light sweater under the coat of his suit. With his death Yale and New Haven have lost one of the last of the old-time gentleman scholars who contributed so largely to their fame.

Many honors came his way. We cannot do better here than to quote the concluding paragraph of Professor Schuchert's memoir.<sup>1</sup>

<sup>1</sup> *Am. Jour. Sci.*, vol. 30, p. 161, 1935.

“His election as corresponding member of the Vienna Reichsanstalt came in 1874, and this same year he was elected to the Sociedad Mexicana de Historia Natural. At the age of thirty-four, he was placed on the roster of honorary members of the ancient Mineralogical Society of St. Petersburg. Acclaim in his own country came also in that year, with his election to the National Academy of Sciences, the greatest honor that can be given to an American scientist. At his death, he was the second oldest member, the oldest one having been elected in 1883. He was also an honorary member of the American Academy of Arts and Sciences (Boston), the American Philosophical Society (Philadelphia), the Geological Society of America, and the Physical Society of America; a foreign member (1894) of the Geological Society, London (corresponding member 1888); and a member of the Edinburgh Geological Society, the Mineralogical Society of Great Britain, the Philosophical Society (Cambridge), and the Vienna Academy. He was honored at the 300th anniversary of the University of Dublin. In 1925, the Mineralogical Society of America elected him Honorary President for life; in 1934 the Mineralogical Club of New York City made him an honorary life member, and the American Museum of Natural History gave him the same distinction. The Yale Corporation, meeting on the day of his death, passed a resolution of which the following are the closing words: ‘Foremost American mineralogist of his time, he brought to himself and to the University widespread recognition in the world of science’.”

## MEMORIAL OF CHARLES HENRY RICHARDSON

L. W. CURRIER, *U. S. Geological Survey,*  
*Washington, D. C.*

Professor Charles Henry Richardson died at Syracuse, New York, on September 19, 1935, at the age of 73. He was a fellow and charter member of the Mineralogical Society of America, and until very recent years had been a constant attendant at its annual meetings, from which he always derived a large measure of profit and enjoyment. He was also a fellow of the Geological Society of America, and a member of the American Institute of Mining and Metallurgical Engineers.



CHARLES HENRY RICHARDSON  
1862-1935

For many years he was professor of mineralogy at Syracuse University, and the enthusiasm and interest with which he endowed his courses were gratefully appreciated by his many students. He was an able mineralogist, but he was better known for his teaching in the theoretical field of the science than for his research, for he chose to employ his knowledge and ability in the fields of applied economic mineralogy and geology, leaving problems of laboratory research to those who had far better facilities at their disposal. He keenly felt the lack of necessary equipment for fundamental research, but with a characteristic optimism directed his energies into active field work. His training in the earth sciences was



broad and varied, and enabled him to bring to his classroom and field work a high degree of collateral knowledge and a wealth of experience.

Doctor Richardson was born in Topsham, Vermont, on September 26, 1862. His childhood was spent amid the rigorous environment and vicissitudes of a small Vermont farm. His early education was fitful at the "little red schoolhouse," where the terms were short and interrupted. At the age of twenty he had never been farther away from home than Montpelier, 18 miles distant, and had never been in either a grammar or a high school. Yet he decided that he wanted a college education and proceeded to lay plans to obtain one. Though his ambition was frowned upon at home, his father subsidized the project with an old valise "that he said he would never want again." With a bare 35 cents in the pockets of his homemade clothes the ambitious boy started out on foot, as uncertain about his destination as he was certain about his goal. He landed at Montpelier Seminary "and registered, I believe, as the greenest country boy ever entering the school." Except for an occasional box from home, he boarded himself, and, as he relates, "I cooked everything I ate, but did not eat everything I cooked. My brown bread crusts were better fitted to hurl on the heads of students three stories below 'nigger heaven' where I roomed."

After four years at Montpelier he went to Bates College at Lewiston, Maine, where there seemed to be more opportunities for earning his way. At Lewiston, whenever the need for cash exceeded his meager income, he would sell a short story to one of the typical "home-and-fireside" magazines of the day. Later in his college career he occupied pastorates in nearby churches. After three years of work a period of serious illness ended his studies at Bates and he returned home to recuperate. In January, 1891, he entered Dartmouth College, for which purpose he was able to borrow some money. During the period at Dartmouth he served as supply preacher in local country churches. He graduated from Dartmouth in 1892 with special honors.

On June 16, 1892, he married Katharine May Davis of Corinth, Vermont, also a graduate of Montpelier Seminary. They had one child, a daughter, Evelyn Dee.

Upon graduation from Dartmouth he was appointed principal of Black River Academy, at Ludlow, Vermont, and next year was called to the principalship of Green Mountain Academy at Waterbury, Vermont.

It is not clear when he began to take a particular interest in minerals and rocks. To a boy of his ambitions, brought up among the rocky hills of the Green Mountain State there must have come an early questioning. Perhaps a long dormant interest was aroused on the numerous

hikes when, as Academy principal, he led a little band of his pupils up the rugged slopes of his beloved Green Mountain peaks, Mt. Mansfield and Camel's Hump, and tried, as he records, to answer their eager questionings. At any rate he returned to Dartmouth for graduate work in chemistry and geology. Although his teaching fellowship, which he held for three years, was in chemistry, he definitely entered the field of geology under the tutelage of Prof. C. H. Hitchcock, and in 1898 presented a dissertation, "The terranes of Orange County, Vermont," for which he received the degree of doctor of philosophy. Four years later he spent a semester at the University of Chicago studying under T. C. Chamberlain, R. D. Salisbury, and J. P. Iddings. In 1906 he spent half a year at Johns Hopkins University.

From 1898 to 1906 he was an instructor in chemistry at Dartmouth College, with some work in mineralogy and geology. In 1906 he was appointed assistant professor of mineralogy at Syracuse University, and in 1909 became professor and head of the newly established department of mineralogy at that institution. In 1933 he was retired as professor emeritus but was given the privilege of continuing to teach one course in mineralogy. He greatly appreciated this permission for he loved the contacts that teaching affords. He has said many times "The saddest thing to me is the fact that we must grow old and lose somewhat the contact with youth."

He was an honored member of Sigma Alpha Epsilon fraternity and served prominently for many years as chairman of the national scholarship committee. He felt honored by election to membership in fourteen scientific, professional, and honorary fraternities, but probably his greatest gratification came in 1932 when he was given an honorary degree of Doctor of Science by Norwich University.

In the course of his professional experience he examined many mining properties in the United States, Canada, and Mexico. His chief interests lay, however, in the geological problems of Vermont, and for forty years he served as a geologist on the Vermont Geological Survey. In this capacity he made his greatest contribution to the science, for he recognized the Ordovician age of certain formations of eastern Vermont, and traced them and the contact with beds of probable Cambrian age from the Canadian boundary to the Massachusetts line. His finding of certain graptolites in the northern part of the State established the age of the beds, and his mapping has laid the foundation for later work on the stratigraphy and structure of the metamorphic belt in eastern Vermont.

His professional writings numbered 45 titles, chiefly in areal geology and non-metallic mineral resources. In addition to this bibliography are 32 published titles relating to education, fraternity problems, book

reviews, and museum reports. Short stories, and an as yet unpublished book of verses entitled "Songs of a Scientist" complete the list of his authorship.

Doctor Richardson lived a full and varied life. The hardships he had undergone in his earlier days served only to increase his helpful and sympathetic understanding of others. He was tolerant almost to a fault. He was a conscientious citizen. A man of integrity, with fine ideals, and unselfish; devoted to his family, and thoughtful of his friends; beloved teacher and adviser, his passing will be felt by many, and memory of him will live in their hearts.

He was buried among the hills of his beloved Vermont.

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# PROCEEDINGS OF THE SIXTEENTH ANNUAL MEETING OF THE MINERALOGICAL SOCIETY OF AMERICA AT NEW YORK, NEW YORK

PAUL F. KERR, *Secretary.*

The sixteenth annual meeting of the Society was called to order Thursday, December 26th, at 1:30 P.M., in the Jade Room of the Waldorf-Astoria Hotel, 50th Street and Park Avenue, New York City, President Clarence S. Ross presiding. The customary business of the Society was conducted, including reports by the officers of the Society and committees summarized as follows:

MINUTES OF THE LAST ANNUAL MEETING.

REPORT OF THE SECRETARY.

REPORT OF THE EDITOR.

REPORT OF THE TREASURER.

MEMORIALS:

A brief oral tribute was presented by Dean Edward H. Kraus of the University of Michigan, for E. S. Dana, late Honorary President of the Society, and C. H. Richardson, late Fellow of the Society.

REPORTS OF COMMITTEES:

Auditing Committee: Read by W. S. Burbank.

Committee on Nomenclature: The Chairman, Dr. Waldemar T. Schaller, requested that action be deferred on the report of the Committee on Nomenclature until the fellows and members of the Mineralogical Society had ample opportunity to read and discuss the report. The complete report is printed in this issue of the Journal.

The business meeting was adjourned at 2:00 P.M. and the President, Clarence S. Ross, called for the presentation of papers.

The report of the election of officers and fellows for 1936, the report of the Secretary, Editor and Treasurer, and the Report of the Auditing Committee are given in the following pages.

## ELECTION OF OFFICERS AND FELLOWS FOR 1935

The Secretary announced that 185 ballots had been cast unanimously for the officers as nominated by the Council. Officers were declared elected as follows:

*President:* William S. Bayley, University of Illinois, Urbana, Illinois.

*Vice-President:* Harold L. Alling, University of Rochester, Rochester, New York.

*Treasurer:* Waldemar T. Schaller, U. S. Geological Survey, Washington, D. C.

*Secretary:* Paul F. Kerr, Columbia University, New York City.

*Editor:* Walter F. Hunt, University of Michigan, Ann Arbor, Michigan.

*Councilor, 1936-1939:* Arthur F. Buddington, Princeton University, Princeton, New Jersey.

The Secretary announced that 76 ballots of fellows had been cast unanimously for nominees for fellowship previously approved by the Council. Newly elected fellows were reported as follows:

Alan Mara Bateman, Yale University, New Haven, Connecticut.  
 Charles H. Behre, Northwestern University, Evanston, Illinois.  
 Ian Campbell, California Institute of Technology, Pasadena, California.  
 Louis W. Currier, U. S. Geological Survey, Washington, D. C.  
 J. G. Fairchild, U. S. Geological Survey, Washington, D. C.  
 Lloyd W. Fisher, Bates College, Lewiston, Maine.  
 Jewell J. Glass, U. S. Geological Survey, Washington, D. C.  
 Ralph E. Grim, Illinois Geological Survey, Urbana, Illinois.  
 Harry H. Hess, Princeton University, New Jersey.  
 Adolph Knopf, Yale University, New Haven, Connecticut.  
 Evans B. Mayo, Cornell University, Ithaca, New York.  
 Arthur A. Pegau, University of Virginia, Charlottesville, Virginia.  
 Alfred K. Snelgrove, Princeton University, Princeton, New Jersey.

## REPORT OF THE SECRETARY FOR 1935

*To the Council and Members of the Mineralogical Society of America:*

The Secretary reports the statistics concerning the membership roll of the Society for the last twelve months as follows:

## MEMBERSHIP STATISTICS

	December 1934	December 1935
Honorary Fellows	4	4
Fellows	125	132
Members	291	336
Subscribers	268	281
	<hr/> 688	<hr/> 753

## GAIN AND LOSS FOR 1935

	GAIN	Loss
Honorary Fellows		
Fellows (not including members elected fellows)		3
Members	78	23
Subscribers	35	22
	<hr/> 113	<hr/> 48

It is interesting to note that the Society has made a net gain in membership of 65 or almost 9 per cent on the basis of the 1934 total. It should be recorded, however, that although both members and subscribers have shown an increase over the previous year, the increase in members has been proportionately greater than the increase in subscribers. This appears to be due to the increasing interest manifest in the Society on the part of those interested in the science of mineralogy.

A total of about seven hundred and fifty paid copies of *The American Mineralogist* is mailed monthly. These are distributed not only throughout the United States and Canada but a constantly increasing number of copies go abroad.

Respectfully submitted

PAUL F. KERR, *Secretary*



## REPORT OF THE EDITOR FOR 1935

*To the Council, Fellows and Members of The Mineralogical Society of America:*

The current year marks the close of the twentieth volume of *The American Mineralogist*. It is very gratifying to recall that during this twenty year period substantial improvements have been made not only in the character of the periodical, but there has been likewise a steady and remarkable growth in the size of the Journal which has culminated in a volume of 900 pages for the present year—an increase of approximately 50 per cent over that of a year ago.

With our very modest subscription price and limited membership it is quite evident that such expansion could not have been possible had we been compelled to rely exclusively upon the income derived from dues, subscriptions, and from incidentals, such as the sale of back numbers and advertising space. In fact this past year the income from the sources just mentioned would have paid only 40 per cent of the total costs. However, funds derived from the interest on the Roebling endowment, and in addition some financial assistance received from the Geological Society of America during the past two years, have made it possible to carry out our expanded program without incurring debts. The Council of the G.S.A. at a meeting held last October voted to recommend the continuance of this assistance during 1936.

It was indicated a year ago that efforts would be made to issue a carefully prepared bibliography and subject index covering the first twenty volumes of the Journal. Under the direction of Mr. J. M. Nickles, who has been placed in charge of this project, rapid progress has been made and indications point to the completion of this work in the near future. The index will include not only authors' names and the titles of papers that have appeared in *The American Mineralogist*, but each article has been read and every mineral indexed for which new data are recorded. It is apparent that such an undertaking is one of major importance and every mineralogist who uses the Journal as a work of reference will find this index indispensable. Due to the heavy cost involved in its preparation and printing it will be necessary to make a small charge for those desiring copies. It is suggested that orders be placed with Dr. Schaller now as the size of the edition must be determined to some extent by the number of advance orders.

As mentioned above volume 20 is by far the largest volume issued by the Society up to the present time. The 12 issues, averaging 75 pages each, contain 62 leading articles. It might be of some interest to note that the average length of the leading articles is about 12 printed pages, although some papers were considerably longer. These contributions came from widely scattered sources and were received from 35 different Universities, research bureaus and technical laboratories. One University supplied 11 leading articles. In addition to these main articles 32 somewhat shorter contributions were accepted, making a total for the year of 94 published manuscripts that were received from 100 contributors. As in the past the manuscripts were not confined to the States. This year four were received from Canada and one each from Italy, China and Soviet Russia: making a total of seven foreign contributions.

As the recording of new minerals is always of considerable interest to the mineralogist a brief survey should recall to mind the four new minerals that have been described in detail this current year—burkeite, austinite, lindgrenite and steigerite.

In the table that forms a part of this report an attempt has been made to classify the 62 leading articles according to the following eight special fields: descriptive, chemical and optical mineralogy; geometrical and structural crystallography; mineralography; petrography; and memorials.

Members of the Council are agreed that the appearance of the Journal could be considerably improved by adopting a larger page and changing to a square back with stitched

binding instead of the stapled form how being used. These alterations however would involve additional expense and after careful consideration it was decided not to make any major changes during 1936, but to defer action until all our present commitments have been met, after which it could be determined more accurately what additional financial burdens, if any, could be safely assumed.

The concluding table of contents summarizes the distribution of subject matter in volume 20.

## DISTRIBUTION OF SUBJECT MATTER IN VOLUME 20

<i>Subjects</i>	<i>Articles</i>	<i>Pages</i>	<i>Per Cent of Total</i>
Leading articles			
Descriptive mineralogy.....	18		
Chemical mineralogy.....	5		
Optical mineralogy.....	4		
Mineralography.....	3		
Structural crystallography.....	11		
Geometrical crystallography....	6		
Petrography.....	12		
Memorials, etc.....	3		
	62	708	79.9
Proceedings of societies.....	23	54½	
Short articles.....	32	96½	
Notes and news.....	8	8½	
Abstracts of new mineral names.....	31	11½	
Book reviews.....	8	7	
	164	886	100.0
Illustrations.....	245		
Covers, advertisements, index.....		134	
Total.....		1020	

Respectfully submitted,  
WALTER F. HUNT, *Editor*.

## REPORT OF THE TREASURER FOR 1935

*To the Council of the Mineralogical Society of America:* Your Treasurer submits herewith his annual report for the year beginning December 1, 1934, and ending November 30, 1935.

## RECEIPTS

Cash on hand December 1, 1934.....	\$1,828.76
Dues and subscriptions.....	2,131.65
Advertisements.....	510.48
Sale of back numbers.....	266.20
Author's charges on separates.....	590.39
Interest on endowment.....	2,339.36
Advance order for index.....	1.00
Sale of Liberty bonds.....	403.50
Geological Society of America refund on dues for 1934.....	132.00
Geological Society of America grant for 1934.....	1,500.00
Geological Society of America grant for 1935.....	1,500.00
	<u>\$11,203.34</u>

## DISBURSEMENTS

Printing and distribution of the Journal (12 issues).....	\$4,822.64
Printing and distribution of separates.....	730.19
To the Editor, Secretary, and Treasurer.....	720.00
Postage.....	90.06
Printing.....	104.31
Clerical help.....	319.07
Committee expenses.....	2.90
Safety deposit box.....	8.25
Bank collecting charges.....	1.87
Check tax (December, 1934).....	0.08
Telegrams.....	1.83
Roebing Medal Fund.....	100.00
Shelves for storing the Journal.....	15.50
Purchase of Union Pacific bond (to replace Liberty bonds)...	545.84
Preparation of 20-volume index.....	660.00
	<u>\$8,122.54</u>
Cash balance November 30, 1935.....	<u>\$3,080.80</u>

\$11,203.34

Of this balance of \$3,080.80 there is allocated the sum of \$800.00 for cost of printing the 20-volume Index of *The American Mineralogist* in 1936, leaving an available balance of \$2,280.80.

The endowment funds of the Society as of November 30, 1935, consist of the following securities, the four Liberty bonds previously held having been called and from the proceeds (\$403.50), with an addition from the Treasury of the Society of \$142.34, one \$500 bond of the Union Pacific Railroad was purchased.

4 \$100 bonds, Great Northern Railway Co., Genl. mtg., 5½%, due January 1, 1952.....	\$ 400.00
1 \$500 bond, Union Pacific R. R., Lien & ref. mtg., 4%, due June 1, 2008....	500.00
1 \$1,000 bond, The Denver Gas & Electric Light Co., First & ref. mtg., 5%, due May 1, 1951.....	1,000.00
2 \$1,000 Certificates, The Trenton Mortgage & Title Guaranty Co., First mtg., 5½%, due November 1, 1937.....	2,000.00
2 \$1,000 Certificates, The Trenton Mortgage & Title Guaranty Co., First mtg., 5½%, due April 1 and December 1, 1938.....	2,000.00
45 \$1,000 bonds, City & County of Honolulu, Hawaii, Water Works, 5%, due April 15, 1954.....	45,000.00
	<u>\$50,900.00</u>

In addition there is \$300.00 in U.S. Postal Savings bonds laid aside for the Roebing Medal Fund.

Respectfully submitted,

W. T. SCHALLER, *Treasurer*

Statement of Special Fund of the Mineralogical Society of America, which is used to support the Berwerth family in Vienna. This fund and its disbursement were initiated by Prof. E. S. Dana and on his death the care and disbursement of the fund have been transferred to the Treasurer of the Mineralogical Society of America.

Available balance as of November 30, 1935, \$1,397.71.

W. T. SCHALLER, *Treasurer*



## REPORT OF THE COMMITTEE ON NOMENCLATURE

*To the Fellows and Members of the Mineralogical Society of America:*

Herewith is presented the second report of the Committee on Nomenclature. The term "nomenclature" is used in a broad sense for the sake of brevity and is intended to cover several subjects. Though based on the report circulated among the membership of the Society in the fall of 1932, it has been considerably changed therefrom, new matter added, old material deleted, and the results of the second meeting, as a joint session with the similar British sub-committee, incorporated.

It was decided at the annual meeting held in New York City, December 26, 1935, to postpone action on its adoption to December 1936. The members of the Society will thus have more time in which to consider the report. Please write the Chairman, Dr. W. T. Schaller, U. S. Geological Survey, Washington, D. C., concerning any changes, or modifications, or new items, you may wish to present.

It is hoped that the full Committee may meet again sometime this coming summer (1936), especially in cooperation with those in charge of and contributing to the preparation of the 7th edition of Dana's *System of Mineralogy*, and others interested, and that a third and final report will be sent to all members of the Society early in the fall of this year.

Your Committee has held three meetings, the first in Toronto on December 28, 1930; the second in Washington (joint session with the British sub-committee) on July 25, 1933; and the third in Washington on April 26, 1935. At no meeting has it been possible for all members of the Committee (Dr. W. F. Foshag, Prof. E. S. Larsen, Dr. J. F. Schairer, Dr. W. T. Schaller, Prof. T. L. Walker, Prof. E. T. Wherry, and Prof. A. N. Winchell) to attend. At the first meeting Professor Wherry, at the second meeting Professor Winchell and Doctor Foshag, and at the third meeting Professors Walker and Wherry, were unable to be present.

The report of the first meeting was sent to the members of the Society in the fall of 1932.

The second meeting was held during the sessions of the 16th International Geological Congress, in Washington, D. C., on July 25, 1933, in joint session with a British Sub-Committee, representing the Mineralogical Society of Great Britain and Ireland. The British Sub-Committee consisted of Sir John Flett, Director of the Geological Survey of Great Britain, Chairman; Mr. W. Campbell Smith of the Mineral Department, British Museum; and Prof. Charles G. Cullis, Professor of Economic Mineralogy, Imperial College of Science and Technology, London.

The wide distribution of the American publications in economic and mining geology in Great Britain and its Colonies has had an important influence in spreading the American usage in words and spelling throughout the world. The marked tendency of the members of the British Committee to accept the widespread usage of terms as published in American journals greatly facilitated the progress of arriving at uniformity and has considerably increased the hope of agreement of English-speaking peoples in the use of scientific terms.

Shortly after their return to Great Britain the British Sub-Committee, which met with us in joint session in Washington, submitted a report of the results of the joint session to the Nomenclature Committee of the British Mineralogical Society (Sir John S. Flett, Chairman, Sir Henry A. Miers, Dr. L. J. Spencer, and Mr. W. Campbell Smith). It is very gratifying to note that this British Committee approved almost entirely the conclusions arrived at by the Washington joint meeting. The British Committee notes that no attempt at international agreement was made. As the results of such earlier attempts at international agreement by the British Committee were futile, your Committee feels that such attempts may not at present be successful and joined heartily with the British Committee in concentrating attention on obtaining uniformity in English-speaking countries.

At the third meeting of your Committee the results of the second meeting were read and discussed and certain changes were made in the report of the first meeting, in part due to the reply made by the British Committee of the results obtained at the joint session of the British and American Committees.

At the first meeting held in Toronto it was agreed that no recommendation would be made unless the Committee approved unanimously, and that any adopted suggestion should make as little change in existing conditions as possible, striving for simplicity and clearness. Well established practice or usage should not be changed. This attitude is in agreement with that of L. J. Spencer (London) who has written "Anything that is done must be quite simple and in gradual and persuasive (give and take) steps. It is not the slightest use to propose any drastic changes."

No subject should be discussed unless there seems to be a good chance of "putting it across" and adopting the conclusion in our Society by giving our Editor authority to enforce our decisions in his editorial work on *The American Mineralogist*. A copy of this report, if adopted by the Society, should be sent to the editors of similar journals (*American Journal of Science, Economic Geology*, etc.) with a request that they likewise follow our decisions editorially.

The Committee presents the various items discussed under three heads: I. Review of former Committee reports (1921-1924); II. New items; III. The symbolism for the indices of refraction and vibration directions.

The items under headings I and II have the unanimous approval of the entire Committee and therefore are recommended for adoption by the Society. The item under III was unanimously approved by those present at the joint session with the British but does not carry the approval of all the members of the Committee and hence is not recommended.

#### I. REVIEW OF FORMER COMMITTEE REPORTS (1921-1924)

1. Definition of mineral species, subspecies, and variety. (*The American Mineralogist*, vol. 8, p. 50, March, 1923.) No action was taken on the definition of the terms species, subspecies, and variety. The use of subspecies should be restricted as much as practical and variety names of a strictly mineralogical nature may gradually disappear if a descriptive phrase, like that proposed by Schaller in *The American Mineralogist*, vol. 15, pp. 566-674, December, 1930, be adopted. See under II (1) below. Some variety names such as ruby, emerald, etc., should remain.

2. Termination of mineral names. (*The American Mineralogist*, vol. 8, pp. 50-52, 1923.) The Committee is in general strongly opposed to changing existing names in common usage. It does not approve either the former minority report favoring changes (realgar to realgarite, rutile to rutilite, corundum to cordundite, etc.) or the former majority report on similar changes for 43 mineral names ending otherwise than in *ite*, such as galena to galenite, trona to tronite, cinnabar to cinnabarite, etc. The Committee recommends that authors use the ending *ite* whenever possible, in the coining of new mineral names, though other endings, such as *ine*, may be used.

3. Spelling of mineral names. (*The American Mineralogist*, vol. 9, pp. 60-63, March, 1924.) All five numbered suggestions of the preliminary mimeographed report are approved. Also the additional items (6 and 7). These are printed in *The American Mineralogist*, vol. 9, p. 61. The alternative spellings of the 57 names listed in the preliminary report are approved with the following exceptions. Salammoniac is preferred to salammonite, cerusite and hydrocerusite (one *s*) are wrong if the name is derived from Latin cerussa, and luenebergite should be spelled lueneburgite.

4 and 5. The Committee makes no recommendation on (4) Division into classes, or (5) Numbering of species.

6. Nomenclature of isomorphous groups. In general agreement with earlier report, with no specific recommendations. Latitude must be allowed for future development.

7. Pronunciation of mineral names. This Committee recommends that a new Committee be appointed to consider the question of pronunciation in cooperation with the British. The British Sub-Committee was very anxious to reach an agreement on this question.

8. Subdivision of mineral classes. This Committee makes no recommendation.

## II. NEW ITEMS

1. The Committee recommends the adoption of Schaller's proposal on the use of a uniform adjectival ending for the names of chemical elements used as modifiers to mineral names, as published in *The American Mineralogist*, vol. 15, pp. 571, 572, December, 1930. The British Committee took no action on this question, at first considering it too artificial an attempt at word building, but on further discussion they decided to hold the matter in abeyance.

2. Use of standard abbreviations (symbols) for physical and optical properties.

(a) Your Committee recommends the use of the abbreviation G in place of D or Sp. Gr., thus obviating discussion as to whether value given represents density or specific gravity. The British Committee reports that the particular abbreviation used "is really a trivial point and can give rise to no ambiguity; but in original papers it should be made quite clear if the correction  $d_4^{20}$  has been applied."

(b) Both your Committee and the British Committee recommend the use of the lower case italic English letters "*r*" and "*v*" for expressing dispersion, instead of the Greek letters rho and upsilon.

3. (a) Crystallographical nomenclature. The Committee recommends the following names for the six systems: Isometric (abbrev. I) instead of cubic, tetragonal instead of quadratic, hexagonal (abbrev. H), orthorhombic (abbrev. O), monoclinic (abbrev. M), and triclinic (abbrev. T) instead of anorthic. The British Committee agreed to triclinic for anorthic and had no real objection to isometric but preferred cubic.

Your Committee does not approve of the use of XYZ instead of *abc* for the three crystal axes.

(b) The Committee feels it is not yet time for definite approval of any one scheme of nomenclature for the 32 classes. In general, it suggests that Dana be followed. The new names which recently appeared in *The American Mineralogist* are not formally adopted by the Committee. This is without prejudice—the Committee feels that it is not yet time for a formal adoption of any one scheme.

(c) The Committee fully approves of Spencer's statement that "Standardization and agreement are also much needed for the orientation, axes of reference, and the letters assigned to the crystal forms of each mineral species."

4. Names of species. Your Committee and the British Committee both recommend the following names and spellings of mineral species. The names to be discarded are placed in parentheses. Some of these names have been discussed by the Committees on account of previous attempts to recommend the names and spellings now recommended to be discarded.

The confusion in the use of the two names calamine and smithsonite in the English-speaking countries should now end. Among the British calamine has been used where we use smithsonite, and smithsonite where we use calamine. By mutual agreement the term calamine is now dropped as a mineral species name. Hemimorphite is approved by both Committees as the name for the zinc silicate,  $H_2Zn_2SiO_6$ , and smithsonite for the zinc carbonate,  $ZnCO_3$ .



Analcime (analcite)	Idocrase (vesuvianite)
Anatase (octahedrite)	Kyanite (cyanite)
Argentite (argyrite)	Labradorite (labrador)
Arsenopyrite (mispickel)	Magnesite, Magnesium carbonate
Autunite (calcouranite)	Nepheline (nephelite)
Azurite (chessylite)	Olivine (chrysolite)
Bornite (erubescite)	Orthoclase (orthoklase)
Chabazite (chabasite)	Phenakite (phenacite)
Chalcopyrite (chalkopyrite)	Plagioclase (plagioklase)
Chrysoberyl (cymophane)	Pyrite (pyrites, iron-pyrites)
Cinnabar (cinnabarite)	Scapolite (wernerite)
Cordierite (iolite, dichroite)	Sepiolite (meerschauum)
Euclase (euklase)	Sillimanite (fibrolite)
Feldspar (feldspat, felspar)	Smithsonite, Zinc carbonate
Fluorite (fluorspar)	Sphene (titanite)
Gypsum (gypsite)	Spodumene (triphane)
Halite (salt, rock-salt)	Stibnite (antimonite)
Hematite (haematite)	Torbernite (cuprouranite)
Hemimorphite (calamine) Zinc silicate	

A few of the approved names may seem unusual to some of our members, but the British Committee was most generous in yielding some of their preferred names. The compromise list is an example of the benefits to be derived from a mutual "give and take" policy.

5. Cooperation with the authors of the proposed new (7th) edition of Dana's *System of Mineralogy*.

Dr. Schairer reported that Prof. W. E. Ford, Editor-in-Chief of the new edition, would adopt any recommendations unanimously made by this Committee and approved by our Society. Several other authors of standard books in mineralogy (Larsen, Winchell) have expressed similar views.

### III. SYMBOLISM OF THE INDICES OF REFRACTION AND VIBRATION DIRECTIONS

At the second meeting of your Committee it was approved unanimously by those present in joint session with the British to adopt alpha, beta, and gamma as the symbols for both indices of refraction and vibration directions. This does not, however, have the approval of all seven members of your Committee and therefore is not recommended.

The Committee recognizes that there are other items worthy of consideration which have not been acted on. They do feel, however, that considerable progress has been made. Perhaps its greatest achievement has been in its success at arriving at agreement on several questions with the British, so that uniformity in usage in great part seems assured, at least with the English-speaking people of the world.

Respectfully submitted,

W. F. FOSHAG  
E. S. LARSEN  
J. F. SCHAIRER  
W. T. SCHALLER, *Chairman*  
T. L. WALKER  
E. T. WHERRY  
A. N. WINCHELL

## PRESENTATION OF PAPERS

The address of Dr. Clarence S. Ross, retiring President of the Mineralogical Society of America, was delivered Friday, December 27 at 11:10 A.M. in the Grand Ballroom before the joint assembly of all societies. The address is printed in full in this issue of the Journal.

## MINERALIZATION IN THE VIRGINIA TITANIUM DEPOSITS

BY CLARENCE S. ROSS, *Washington, D. C.*

*(Abstract)*

The titanium region of Nelson and Amherst Counties, Virginia, is the world's largest producer of rutile, and also has large supplies of ilmenite. The titanium ores are associated with a feldspathic rock. However, they were probably derived from a deep-seated, highly ferromagnesian rock, of which only a few highly altered and mineralized apophyses reach the surface. The feldspathic rock was intruded as a mush of crystals, and thoroughly granulated during the process. Therefore, the relations are those of an anorthosite, although the plagioclase is andesine, rather than labradorite.

The titanium ores occur as disseminations in the feldspathic rock; and as dike or vein-like lenses which are largely confined to this rock. Both types of ore were deposited by invading solutions, since they were formed after the intrusion and granulation of the feldspathic rock.

A group of associated secondary silicates show that the introduced materials were titanium, ferric iron, magnesium, and very minor amounts of silica and alkalis. The simple chemical composition of the replaced feldspathic rock and the small number of introduced elements presents an unusually favorable opportunity for the study of the chemistry of mineralization. Near feeding channels, a restricted zone of iron-bearing minerals formed; farther out magnesian minerals and iron-free rutile were deposited, and almost throughout the granulated feldspar rock important mineral changes occurred without marked transfer of materials.

## THE ORIGIN OF KERNITE AND BORAX IN THE KRAMER BORATE FIELD, CALIFORNIA

BY WALDEMAR T. SCHALLER

*Presented on program of General Session, Geological Society of America, by invitation*

The sodium borates (kernite and borax) of the Kramer borate field, Mohave Desert, Calif., lie from 350 to 800 feet underground in bedded Tertiary clay deposits. The buried borate basin is about four miles long and one mile wide. The deposits of kernite and borax are about 100 feet thick and consist of about 75 per cent of sodium borates. Ulexite and colemanite beds occur above and below the kernite and borax.

In one of the three mines, where the continuous and parallel clay layers are neither folded nor broken, borax is the only sodium borate present. In the other two mines, where the clay layers are folded and considerably broken, kernite is present in millions of tons, in large and small crystals. In places the clay beds have been pushed aside and molded around the kernite crystals. The kernite has formed from the borax by recrystallization due to increased temperature and pressure.

The deposit is unusual in the absence of other saline minerals, such as the carbonate, chloride, and sulphate of sodium, calcium, and magnesium. A derivation of the borax from the change of ulexite to colemanite would yield borax free from these other saline minerals. The known extent of the ulexite-colemanite deposits is sufficient to furnish the known quantity of borax and kernite.

## MINERALOGY AND PHYSICAL-CHEMICAL MINERALOGY

*Thursday Afternoon, December 26th*

## PSEUDOWOLLASTONITE AND WOLLASTONITE SOLID SOLUTIONS WITH DIOPSIDE AND AKERMANITE, by J. F. Schairer and N. L. Bowen.

Recent detailed laboratory studies of the systems,  $\text{CaSiO}_3\text{-CaMgSi}_2\text{O}_6$  and  $\text{CaSiO}_3\text{-Ca}_2\text{MgSi}_2\text{O}_7$ , show that both systems are binary.

Wollastonite ( $\beta\text{-CaSiO}_3$ ) forms a series of solid solutions with diopside ( $\text{CaMgSi}_2\text{O}_6$ ) extending to about 22 per cent diopside. Pseudowollastonite ( $\alpha\text{-CaSiO}_3$ ) takes little if any diopside into solid solution. As a consequence of this difference in concentration of the solid solutions the inversion wollastonite  $\rightleftharpoons$  pseudowollastonite is raised from about 1130°C. to 1368°C. and wollastonite solid solutions appear in equilibrium with liquid. The eutectic between pure diopside and wollastonite solid solution is at 1358°C. and 62 weight per cent diopside.

The system,  $\text{CaSiO}_3\text{-Ca}_2\text{MgSi}_2\text{O}_7$  (akermanite), is of the simple eutectic type with no solid solution. There is a eutectic between  $\alpha\text{-CaSiO}_3$  and akermanite at 1398°C. and 57 weight per cent akermanite. The inversion of  $\beta\text{-CaSiO}_3$  to  $\alpha\text{-CaSiO}_3$  is at about 1130°C. for all compositions of this system, a reflection of the failure of solid solution of akermanite in both forms of  $\text{CaSiO}_3$ .

## DETERMINATION OF THE MINERAL COMPOSITION OF MINE DUST BY MEANS OF X-RAYS, by T. L. Walker.

Chemical analyses of mine dust and of mill feed from the same mine indicate that certain minerals settle from the air more quickly than others with the result that they form a smaller percentage of the dust than of the ore. This is most marked in the case of quartz. Minerals with best cleavage concentrate in the dust. At the suggestion of the author, experiments were undertaken by Professor G. L. Clark, University of Illinois, which have developed into an established method for determining the amount of quartz in mine dust by means of a study of X-ray diffraction patterns from dust and of the densitometer curves prepared from them. By this method a mixture of crystalline substances may be analysed, giving the per cent of each crystalline component. The accuracy of this method for the determination of quartz has been shown to be within five per cent of the quartz present. It is believed that this method will be of service in the study of dusts which give rise to silicosis.

## BABINGTONITE FROM WESTFIELD, MASSACHUSETTS, by Charles Palache.

Babingtonite was first found at this well-known datolite locality in 1935. Form and chemical composition are practically identical with those recently described for babingtonite from Holyoke. Associated with it are prehnite, datolite, epidote, calcite and quartz. Epidote is of two habits, one very dark and shown by analysis to be richer in iron than any epidote optically studied. The optical data effect slight modification of accepted curves.

## SEPARATION PLANES IN MAGNETITE, by J. W. Grieg, H. E. Merwin and E. Posnjak.

Faces on magnetite crystals may show striations, and pieces, when broken, frequently separate along planes. It has usually been supposed that this was due to spinel twinning, but goniometric observations on crystals and plane faced fragments of magnetite together with microscopic examinations of polished sections of artificially oxidized magnetite show that several planes of separation occur, none of which are necessarily associated with detectable twinning.

## IMMERSION LIQUIDS OF HIGH REFRACTIVE INDEX, by C. D. West.

A set of immersion liquids for the refractive index range  $n_D = 1.78-2.06$ , made up of the components phosphorus, sulfur and methylene iodide, is described. From five months' experience with these liquids it is concluded that they are practically stable and safe to use with proper precautions.

## CHEMICAL COMPOSITION AND OPTICAL PROPERTIES OF SOME CALCIC PLAGIOCLASES, by A. H. Phillips and H. H. Hess.

Chemical analyses and indices of refraction of five calcic plagioclases were presented and discussed. The work was undertaken in an attempt to improve the curves for optical properties at the calcic end of the plagioclase series (labradorite to anorthite). The material was especially collected for this purpose from the Stillwater Igneous Complex of Montana. Separation of the plagioclase from the hypersthene and diallage with which it occurred as well as removal of minute inclusions in some cases present within the plagioclase was accomplished by means of the Frantz isodynamic magnetic separator.

## THE MELTING OF DANBURITE, by G. W. Morey and Earl Ingerson.

Danburite melts with formation of two ternary liquid layers, a type of melting never observed before. The two liquids are one pair of a continuous series of immiscible liquids extending from the binary system,  $\text{CaO-SiO}_2$ , to the binary system,  $\text{CaO-B}_2\text{O}_3$ . In the ternary system, the region of immiscibility extends to regions of higher CaO content than in either of the binary systems. In other words, addition of  $\text{B}_2\text{O}_3$  to the binary system,  $\text{CaO-SiO}_2$ , or of  $\text{SiO}_2$  to the binary system,  $\text{CaO-B}_2\text{O}_3$ , causes the two coexisting liquids to diverge further in composition. Because of the fact that in the one binary system the crystalline phase in equilibrium with two liquid layers is one of the components, silica, while in the other binary system it is the compound,  $\text{CaO} \cdot 2\text{B}_2\text{O}_3$ , the invariant points containing two liquid phases, two crystalline phases and vapor show some novel features, made more interesting by one of the coexisting liquids containing only a small amount of CaO. The effect of adding  $\text{Na}_2\text{O}$ , that is, the surface of separation of the immiscible region in the quaternary system,  $\text{Na}_2\text{O-CaO-B}_2\text{O}_3\text{-SiO}_2$ , has been outlined, and similar experiments are under way in the system,  $\text{H}_2\text{O-CaO-B}_2\text{O}_3$ .

## A THIRD STUDY OF CHLORITE, by A. N. Winchell.

A revised diagram has been prepared showing the relations between variations in composition and in optic properties in the main chlorite system (antigorite-amesite-daphnite-ferroantigorite). The relations between optic properties and the various types of chlorite have been shown in another diagram. A new graph for the antigorite-amesite-kaemmererite system has been prepared. Finally, the effects produced on optic properties by oxidation of ferrous iron in certain chlorites have been expressed graphically.

## MINERALOIDS, by Austin F. Rogers.

It is proposed to use Niedzwiedzki's term *mineraloid* not only for the less definite mineral-like substances such as palagonite, sideromelane, chlorophaeite, volcanic glass, and hydrocarbons (amber, ozokerite, asphaltum, etc.), but also for the more definite amorphous equivalents of crystalline minerals now usually classed as minerals. On account of the variation in both chemical composition and physical properties, these amorphous mineral substances, such as opal, clachite, limonite, and collophane, cannot be as accurately defined as crystalline minerals are. However, they deserve recognition from the scientific as well as the economic standpoint. It seems best to consider them mineraloids rather than minerals proper.



There are two general classes of mineraloids: the hyaline (glasses) and the porodine (hydrogels), to use Breithaupt's terms.

Hyaline mineraloids include lechatelierite, maskelynite, and volcanic glass.

To the porodine mineraloids I would assign patronite, xanthochroite, hydrotroilite, opal, melaconite, pyrolusite, psilomelane, clachite, limonite, collophane, evansite, pitticite, bindheimite, greenalite, hisingerite, neotocite, halloysite, allophane, stevensite, cornuite, and the metamict equivalents of zircon (malacon), thorite, allanite, gadolinite, homilite, yttrotantalite, and yttrocrasite.

HIGH IRON TOURMALINE FROM THE MARQUETTE IRON RANGE, by C. B. Slawson.

Iron tourmaline is a characteristic mineral in the quartz veins of the Marquette iron range. These quartz veins are derived from the Republic batholith lying to the south of the range. Quartz tourmaline veins cutting the magnetite ore bodies of the Greenwood mine show little alteration of the magnetite. Non-tourmaline bearing quartz veins alter the magnetite to specular hematite. Chemical and optical data are given for high iron tourmaline from the Champion iron mine.

DICKITE IN MISSOURI, by W. A. Tarr and W. D. Keller.

The finding of dickite in Missouri is reported for the first time. These new occurrences are described and its mode of occurrence, association with sulphides, and optical properties are given.

MICROCHEMICAL METHODS IN DETERMINATIVE MINERALOGY, by Lloyd W. Staples.

Microchemical methods for the determination of the non-opaque minerals have not received the attention which they deserve. These methods frequently result in a saving of time, labor, and reagents. A comparatively few reagents, most of which are inexpensive and available in blowpipe laboratories, satisfactorily meet most determinative problems. If only small amounts of minerals are available for testing, or in the case of minerals with high indices of refraction, microchemical methods are very valuable. They will probably find their most efficient use in supplementing the study of minerals in crushed fragments by the immersion method.

Microchemical determinative methods are not without their attendant difficulties. These may be due to a variety of causes such as poor technique, difficult solubility of minerals, or lack of good tests for certain elements. In spite of these difficulties, the advantages to be gained from these methods are sufficient to strongly recommend them.

Several new, simplified, or improved tests are discussed. Aluminum, iron, and manganese may be detected by ammonium paramolybdate and the fluosilicate test developed by Boricky and Behrens has been improved so that it provides a simple and adequate test for silicon. Crystalline precipitates are to be preferred to color reactions for most work. The technique of microchemical testing is very important and suggestions regarding improvements and simplification of it are made.

#### CONFERENCE ON METHODS OF MINERAL EXHIBITION

*Thursday, 4:00 P.M., December 26th*

EXPERIMENTS IN MOUNTING MINERALS FOR EXHIBITION, by Charles Palache.

For hand specimens of moderate size a plaque of plaster of Paris is employed, proportioned to the specimen. The plaques are arranged on broad sheets of plaster lining the case. The plaster has a pleasing matte surface, does not discolor with age, is easily cleaned, and gives good spacing to specimens.

Cut stones and small gem crystals are mounted on plaques of colorless plate glass, held by a drop of rubber cement.

**MINERALOGY IN THE COMMERCIAL MUSEUM**, by Charles R. Toothaker.

The mineral exhibits in the Philadelphia Commercial Museum are arranged on a commercial basis, not from the standpoint of scientific mineralogy. They show the ores of the important metals and the various mineral substances which have commercial value. The plan of arrangement begins with iron and follows on with the alloy metals, then lead, silver, copper, gold, aluminum and the rarer metals. Following are such things as mica, asbestos, ceramics, potash, salt and building stones. Petroleum and coal are in a parallel line which puts coal and iron alongside each other.

The Museum displays as a rule fairly large and showy ore specimens and these are, if possible, held in place by invisible wrought iron brackets.

The exhibits are supplemented by a number of miniature models of such things as an iron mine, a blast furnace, an open hearth steel mill, a coke works, a coal mine, a marble quarry, a granite quarry, etc.

**HOW TO MAKE THE PUBLIC OBSERVE AND THINK IN THE MINERAL GALLERY**, by T. L. Walker and A. L. Parsons.

In order to attract visitors to the mineral gallery of the Royal Ontario Museum it has been found useful to have attractive displays visible from the entrance. A case showing the attractive colors of minerals, another showing fluorescence of minerals and an automatic balopticon with pictures connected with the study of minerals serve as efficient baits. A lodestone compass which is known to thousands of school children brings great numbers of visitors. In addition to the systematic collections of minerals and rocks there are series of gem stones, series of genetically related minerals, valuable minerals of Ontario, Canadian minerals and large ore specimens mostly from Ontario. The outstanding feature that characterizes the Royal Ontario Museum of Mineralogy is the series of descriptive labels that are used to call attention to special features in large specimens or series of specimens. Large specimens are put in high cases interspersed in the systematic collections, but no specimen is displayed unless an instructive label can be prepared. Paragenetic series are arranged in large table cases and a single explanatory label describes the association. All labels are printed, and the descriptive labels have sufficient material for an elementary textbook on mineralogy and petrography.

**NEW CASES FOR THE DISPLAY AND STORAGE OF SPECIMENS**, by Samuel G. Gordon.

New low-cost museum cases for more effective display of specimens have been designed. The cases are practically "envelopes" of glass, beveled and grooved to fit together without wood or metal edges, and joined to welded metal bases. The construction admits of 100% lighting and visibility. While all hardware and locks are concealed, provision has been made for easily opening or securely locking the cases. The new designs include wall, table (with horizontal or sloping glass top), floor, and pedestal cases. A storage case, equipped with steel or wooden trays, for compact and economical storage of specimens has also been developed, and cases which combine a display unit with a storage cabinet.

**THE SMALL LABORATORY MUSEUM COLLECTION**, by Austin F. Rogers.

In case there is not sufficient space or funds available for a large museum, it is convenient to install a small museum collection at one end of the laboratory.

In this way the better specimens are protected and the museum collection supplements the study collections to which students are allowed direct access.

THE TEACHING MUSEUM, AN AID TO CLASS INSTRUCTION, by C. B. Slawson and M. V. Denny.

The museum practice as followed in the Mineralogical Museum of the University of Michigan is outlined, especially in reference to the use of material from the museum for lecture, class, and laboratory purposes. A more liberal museum policy is advocated which allows the student the use of museum grade material which is commonly held in reserve as "dead storage."

THE MINERAL MUSEUM AND THE PEOPLE, by H. P. Whitlock.

Deals with the general problems of presentation and crowd psychology including such details as the use of colors in direction arrows and charts, means of breaking monotony in installation and the study of mounts, labels and backgrounds.

## PRESENTATION OF PAPERS

### PETROGRAPHY

*Friday Afternoon, December 27th*

THE DIKES OF CAPE NEDDICK, MAINE, by John C. Haff.

A petrologic study is being made of the dikes of Cape Neddick, Maine, and the adjacent coast. The eastern portion of the Cape is underlain by a gabbro stock of small area which intrudes the Kittery quartzite (Pennsylvanian). There are at least two major hypabyssal successions although others may be distinguished. The older succession consists of diabases, lamprophyres, granophyres and quartz-porphyrries, all of which were intruded into the quartzite prior to the invasion of the gabbro. The younger succession comprises the aplites, bostonites, trachytes, and diorite-porphyrries (among others) which are definitely post-gabbro. Considered as a swarm the dikes in the quartzite strike predominantly N. 50–70° E., making varying angles with the highly foliated quartzite which trends northeasterly. The dikes in the gabbro itself are much more erratic in behavior.

There is a prevalence of complex structural relationships and many breccias are developed. Forty examples of contiguous and partition types of multiple dikes are known. The intrusion of four and five lithologically divergent rocks into one repeatedly eviscerated dike is common. True composite relations are difficult to prove.

The various breccias may be separated into genetic types depending on the source and condition of fragments, mode of emplacement, and localization within dikes or at contacts. Questions of age relationships, of the development of mixed types, and of xenoporphyratic structures are believed to be clarified.

A PECULIAR FORM OF DIFFERENTIATED IGNEOUS INTRUSION, by Bennett Frank Buie.

A dike-like body of shonkinitic rock showing marked differentiation is intrusive into the flat lying sandstone at the east side of the Highwood Mountains, Montana. The upper contact is conformable with the sedimentary bedding, and the rounded top gives the appearance of an aqueduct or a great tube. In cross section the body is bulb shaped, narrowing downward to a feeder dike. The transverse dimension averages about 100 feet. The body has been mapped for a distance of three and one-half miles. Throughout this extent an earlier but related dike, 4 feet to 8 feet wide, cuts the sandstone above and is cut off by the main body of igneous rock.

After emplacement, magmatic differentiation occurred, causing a concentration of 50 per cent of pseudoleucite in the rock near the upper contact, and a concentration of augite in the lower part. The increase in proportion of augite with depth is gradational. The

body is well exposed, and appears to be an excellent example of gravitative differentiation.

The pseudoleucite occurs in trapezohedrons, the marginal portions of which are feldspar. The question of the origin of the pseudoleucite is considered.

A SCHEELITE-LEUCHTENBERGITE DEPOSIT IN THE PARADISE RANGE, by Paul F. Kerr and Eugene Callaghan.

A scheelite-leuchtenbergite vein, about 900 feet in length and averaging about 4 feet in thickness, occurs in the Paradise Range, Nevada. The scheelite was deposited originally with quartz associated with a few crystals of epidote and vesuvianite, under high-temperature conditions of crystallization related to a granodiorite stock not far distant and perhaps more immediately to a perthitic orthoclase dike along the vein. Hydrothermal replacement has left much of the scheelite in lumps surrounded by rims of talc and scattered through a matrix of leuchtenbergite. It is believed that the scheelite in such masses is residual, and that the matrix of quartz in which the scheelite originally occurred has been replaced by talc and leuchtenbergite.

Carbonate rock consisting of both dolomite and magnesite forms the wall rock on both sides of the vein. Remnants of an altered perthitic orthoclase dike occur along the vein. Granophyre dikes cut through both the wall rock and the vein. Postmineral faults follow the vein and branch off into the wall rock in several places.

Scheelite is irregularly distributed in the vein, but the amount so far developed is small.

DIFFERENTIATION IN THE SHONKIN SAG LACCOLITH, by Cornelius S. Hurlbut, Jr.

A remapping of the Shonkin Sag laccolith has shown it to be of much greater areal extent than formerly believed. Good exposures along much of its periphery indicate an almost circular plan. Changes in mineral composition from top to bottom of a single rock layer point to differentiation in place, but in an unusual manner. Several hundred specific gravity determinations show a change in density from top to bottom compatible with the change in mineral composition.

VEIN QUARTZ PSEUDOMORPHOUS AFTER ASBESTIFORM ACTINOLITE FROM THE BLUE RIDGE OF FAUQUIER COUNTY, VIRGINIA, by Lincoln R. Thiesmeyer.

The Blue Ridge in the western part of Fauquier County, Va., is capped by altered amygdaloidal volcanic rocks belonging to the so-called catoctin greenstone. At numerous localities they contain veins of cross-fiber asbestiform actinolite, partially to almost completely replaced by quartz. The veins vary from a few millimeters to fifteen centimeters wide and show a distinct en echelon arrangement. Post-vein deformation is indicated by a pronounced series of monoclinical flexures across the veins. The quartz in these veins consists mostly of coarse, rather brittle fibers, each of which is an aggregate pseudomorph of bundles of actinolite and has inherited the structures of the latter. The quartz fibers are sometimes crowded with hairlike inclusions of actinolite, and residual bundles of this material occur between them. Some recrystallization of actinolite and epidotisation of the wallrock accompanied the replacement. The orientation of vein minerals is discussed.

PLAGIOCLASE, PYROXENE AND OLIVINE VARIATION IN THE STILLWATER COMPLEX, by H. H. Hess.

Detailed changes in the composition of plagioclases, pyroxenes and olivines of the Stillwater Igneous Complex were studied. This complex, a lololith, has been strongly differentiated presumably by crystal sorting and fractional crystallization (J. W. Peoples, 1932). Thus the variation in the pyroxenes from the base of the complex upwards should correspond to the variation of the pyroxenes crystallizing from the magma as differentia-



tion proceeded. Variation in the plagioclases upwards in the lopolith might indicate whether the plagioclase settled or floated in the melt as differentiation took place.

As might be expected, the Mg-Fe ratio of the pyroxenes and olivines decreases from the base of the complex upwards and the ratio of monoclinic pyroxene to orthorhombic pyroxene increases. With a few reversals, the plagioclases change from  $An_{88}$  near the base of the plagioclase-bearing rocks to  $An_{60}$  at the highest point exposed. The reversals appear to be due to additions of new magma.

DEPOSITS OF RADIOACTIVE CERITE NEAR JAMESTOWN, COLORADO, by E. N. Goddard and Jewell J. Glass.

Small deposits of cerite occur in the pre-Cambrian rocks of the Front Range near Jamestown, 9 miles northwest of Boulder, Colorado. They are near the north border of a stock of Silver Plume granite, to which they are genetically related. Linear structures indicate that the stock was intruded steeply from the south and an abundance of lenticular schist areas in the granite suggest proximity to the roof.

The gray to brown cerite occurs as irregular lenses one-fourth to 15 inches wide in narrow aplite-pegmatite zones along the borders of small schist areas. Narrow veinlets of black allanite border the cerite and in places cut through it. Minute grains of pitchblende(?) and of pyrite are locally present.

Microscopic examination of the cerite shows it to be finely intergrown with varying amounts of yttrocerite, törnebohmite, allanite and other rare earth epidotes, parisite, pitchblende(?), and quartz. An analysis of some of the purer cerite showed 56 per cent  $Ce_2O_3$ .

A gray variety consisting of cerite, yttrocerite, and a rare earth epidote was found to show mild radioactivity on a photographic plate. An analysis of this material by J. G. Fairchild showed 28 per cent  $Ce_2O_3$ , 27.20 per cent (La, Tb) $_2O_3$  etc., 2.94 per cent  $Y_2O_3$  etc., 0.513 per cent  $U_3O_8$ , and 0.28 per cent  $ThO_2$ , and gave an age determination of 940,000,000 years. This figure accords with the supposed pre-Cambrian age of the Silver Plume granite and with its field relations to the Pikes Peak granite whose determined age is 1,000,025,000 years.

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## PRESENTATION OF PAPERS

### MINERALOGY, CRYSTALLOGRAPHY, CRYSTAL STRUCTURE AND X-RAY STUDIES

*Saturday Morning, December 28th*

REFRACTIVE INDICES OF NATURAL RESINS, by A. E. Alexander.

Through the courtesy of Dr. Charles L. Mantell and the American Gum Importers Association, Inc., samples of natural resins were forwarded the writer for optical study.

Gums are amorphous and under polarized light such substances react isotropically. They consequently possess only one index of refraction. The indices of refraction of the natural resins, as determined, are:

CW Kauri.....	1.546	Pontianac.....	1.540
#3 Pale Kauri.....	1.546	Loba B. Manila.....	1.539
#3 Brown Kauri.....	1.544	Hard Manila.....	1.539
Pale East India.....	1.543	Bold Damar.....	1.538
Zanzibar.....	1.542	Batu.....	1.538
Ivory Congo.....	1.541	Tacamahac.....	1.538
Dark Congo.....	1.541	Ghatti.....	1.528
Black East India.....	1.541	Senegal.....	1.528
Benguela.....	1.541	Gutta Percha.....	1.528

## MINERALS IN THE BATES LIMESTONE, LEWISTON, MAINE, by Lloyd W. Fisher.

The Bates Limestone of probable Cambro-Ordovician age is intruded by at least 16 basic dikes and two pegmatite dikes in the type locality in the city quarry, Lewiston. The limestone shows varying degrees of metamorphism. In some places, large calcite plates and crystals have developed; in other places diopside has been abundantly formed. Some beds of limestone have been changed to biotite schist. Graphite is abundant in some of the acid intrusives.

The variety and abundance of the various minerals of the limestone have been studied with reference to the effect of the intrusives in the region. The possible effects of contact regional metamorphism are discussed.

## AN OCCURRENCE OF FELDSPARS REPLACING FOSSILS, by Bronson Stringham.

Several rock specimens were collected from the Provo River damsite, Utah. Among these is included an almost pure limestone of Mississippian age, which is tentatively correlated with the Madison formation. The limestone contains fossils and fossil fragments, some of which have been replaced by albite-oligoclase which is in many instances euhedral. Apparently the occurrence of the feldspars is confined to one horizon in the Madison formation.

Inasmuch as there has been no evidence found for the introduction of the feldspar and the fact that no igneous intrusives or mineralization are present in the vicinity, it is suggested that the feldspars are of authigenic origin.

## IDENTIFICATION OF ROCKS BY REFLECTED LIGHT, by Fred E. Wright.

Minerals in the thin section and in powder form are commonly determined by the effects they have on transmitted light. Reflected light is rarely used and then only when observations on transmitted light are not possible, as in the case of lunar surface materials where the observer is restricted to a study of the effects produced by those materials on sun's rays on reflection and to comparison of these effects with those produced by terrestrial materials under similar conditions of illumination. The changes produced on reflection are of two kinds: (a) the relative intensities of light of different wave lengths are altered (selective reflection), and polarized light is introduced. These changes occur both in the visible and in the ultraviolet and infra-red parts of the spectrum. Several different methods have been used for measuring these changes: a visual method, polarization spectrograph, photoelectric cell together with a compound Wollaston prism, vacuum thermoelement with the same Wollaston prism. The percentage polarization of radiant energy in the visible spectrum is best ascertained by use of a special polarization eyepiece; the results obtained with it prove that the amount of plane polarization induced on reflection depends on a number of factors, such as character of material, condition of the reflecting surface, angle between the incident and outgoing rays, wave length of light, and so on. Extended series of measurements have been made on different types of rocks and other substances and the possibilities and limitations of the method thus ascertained.

## ALTERATION OF GABBRO NEAR PHILADELPHIA, PENNSYLVANIA, by E. H. Watson.

Gabbroic rocks are the most abundant intrusives into the crystalline schists and gneisses of southeastern Pennsylvania. The largest body extends as a somewhat discontinuous mass 25 miles westsouthwest from the Schuylkill River to beyond West Chester. Far the greater part of this mass has been altered by later granitic and pegmatitic injections producing composite flow gneisses or migmatites. The injections caused flowage and shearing, and locally developed mylonitized zones. Widespread chemical reaction occurred: plagi-

clase becomes progressively more sodic, accompanying dilution by potash feldspar and quartz; the original pyroxenes of the gabbro are replaced by a reaction series in the order—pyroxene, hornblende, biotite, garnet.

Smaller areas of massive unaltered gabbro are gradational into these composite flow gneisses and the metamorphic structures produced are believed due to injection and not to regional metamorphism. Also, the evidence indicates that the injections, although magmatic in character, were introduced largely in the form of hydrothermal solutions.

#### HYDROTHERMAL ALTERATION OF MONTMORILLONITE TO FELDSPAR AT 245°C. AND 300°C., by John W. Gruner.

Montmorillonite was heated in gold-lined pressure bombs in aqueous solutions of  $\text{KHCO}_3$  (10%). Seven days at 300°C. produced very good orthoclase. The X-ray powder photograph is identical with adularia. At 272°C. the feldspar pattern became distinct after 10 days. At 245°C. the stronger lines of orthoclase appeared after 42 days heating. No changes were noticeable after four weeks at 200°C. KCl solutions do not seem to alter the montmorillonite in 19 days at 300°C.

#### ANORTHITE FROM DUKE ISLAND, ALASKA, by Jewell J. Glass.

During a recent study of the rocks of Duke Island, Alaska, by A. H. Koschmann of the United States Geological Survey, a plagioclase feldspar unusually high in calcium was recognized. Chemical analysis, confirmed by the optical properties, show this feldspar to be an unusually pure ( $\text{An}_{96}$ ) anorthite. The massive feldspar, pearl gray on a freshly broken surface, weathers white and forms bands or vein-like masses intergrown with glossy black crystals of hornblende two feet long. The rock in which the plagioclase occurs is a coarse-grained hornblende pegmatite, striking in appearance.

Plagioclase feldspars high in the anorthite molecule are found rarely in nature. Those to which the Alaskan anorthite are comparable occur as crystals in volcanic bombs.

#### OUTLINE OF A CLASSIFICATION OF THE SILICATES, by Harry Berman.

A chemical classification based on ideas relating to crystal chemistry developed from recent structure studies is proposed for all the silicate minerals. It is shown that the physical properties of each structural type are closely related to the chemical characteristics and are a further indication of the proper position of any silicate in the classification. It is this close relation between physical and chemical characteristics which is the fundamental concept in the classification.

#### OPTICS AND STRUCTURE OF THREE-DIMENSIONAL SPHERULITES, by H. W. Morse and J. D. H. Donnay.

The shape and optical characters of artificial spherulites and related aggregates were studied in order to help elucidate their internal structure. Although these aggregates vary widely in external shape most, if not all, belong to one and the same type of "aggregation," due to radiating crystallization. Observation of possible transitional stages leads to a working hypothesis as to the mechanism of formation of spherulitic structures, *viz.* that a continuous branching out of the fibers makes an aggregate appear like a sheaf of fibers opening at both ends, in fan-like manner, as growth proceeds until spherical shape is reached or approximated.

The optical unit of the structure is the fiber, which behaves like a uniaxial entity. The refractive indices of the fiber, however, differ from those of the crystalline species that builds up the fiber. Various factors are considered in an attempt to explain this discrepancy: (1) crystal orientation along the fiber, (2) presence of a less refracting interstitial

medium, (3) form-birefringence, in case the constituents of the fiber are smaller than the wave length of light.

The circular outline of spherulites, immersed in certain media, appears elliptically distorted. This optical effect, previously observed by Spangenberg, may give information on the fiber indices, not on the indices of the crystals constituting the fiber.

Some of our preparations show the artificial duplication of the "supplemental growth" found by Cross in natural spherulites.

#### ON ROSELITE AND THE RULE OF HIGHEST PSEUDO-SYMMETRY, by M. A. Peacock.

Ill-considered application of the Rule of Highest Pseudo-Symmetry has sometimes led to unsatisfactory crystallographic elements. A clear case is that of roselite,  $6(\text{Ca}, \text{Mg}, \text{Co})\text{O} \cdot 4\text{As}_2\text{O}_5 \cdot 5\text{H}_2\text{O}$ , which Schrauf (1874) referred to pseudo-orthorhombic triclinic elements giving abnormal form symbols. A restudy largely confirms Schrauf's measurements, but leads to monoclinic elements and normal symbols, and indicates that some of Schrauf's forms are fictitious. The conclusion is that the lattice with the highest pseudo-symmetry may be a multiple lattice of the proper crystal lattice.

#### THE CHEMICAL COMPOSITION OF SEPIOLITE (MEERSCHAUM), by W. T. Schaller.

Sepiolite (meerschaum) is supposed to consist of one of two minerals:  $\alpha$ -sepiolite or parasepiolite,  $2\text{MgO} \cdot 3\text{SiO}_2 \cdot 4\text{H}_2\text{O}$ , and  $\beta$ -sepiolite,  $2\text{MgO} \cdot 3\text{SiO}_2 \cdot 2\text{H}_2\text{O}$ . A compilation of 56 analyses shows 15 analyses agreeing with  $\beta$ -sepiolite, 34 analyses agreeing with  $\alpha$ -sepiolite, and 7 intermediate analyses.

A reading of the original papers has shown that all but three of the 15 analyses of  $\beta$ -sepiolite were made on material variously dried (in some samples by heating to  $200^\circ\text{C}.$ ), before analysis, thus expelling half the water content.

Critically reviewing the analyses and making corrections for water loss, there remain only two old analyses supporting  $\beta$ -sepiolite and two intermediate analyses. The remaining analyses support the formula of  $\alpha$ -sepiolite.

There is then only one sepiolite with the formula  $2\text{MgO} \cdot 3\text{SiO}_2 \cdot 4\text{H}_2\text{O}$  and the name parasepiolite, as different from sepiolite, is to be discarded.

#### AN X-RAY STUDY OF ALLEMONTITE, by Ralph J. Holmes.

Kalb, Van der Veen, Walker and others have established the non-homogeneous character of "allemontite" but obtained no conclusive data regarding the nature of either of the two components.

The following conclusions are based on an x-ray study of "allemontite" from Allemont, France; Pribřam, Czechoslovakia; Atlin, B. C.; and Alder Island, B. C.

1. "Allemontite" consists of two components which are apparently identical in all the material studied.

2. One of these components "A" is native arsenic or arsenic bearing an insufficient amount of antimony in solid solution to produce any change in x-ray pattern from that of pure arsenic.

3. The other component "B" is an antimony-arsenic "compound." Whether this is a true chemical compound or a member of a solid solution series is not definitely known.

4. The variable chemical composition of "allemontite" is a consequence of the wide variation in the relative proportions of the components "A" and "B."

5. It is probable that under the original conditions of formation arsenic and antimony formed an unlimited solid solution series. Under changed later conditions only that combination of arsenic and antimony represented by component "B" was stable. Any arsenic present in excess of that necessary to form "B" was released as free arsenic.



6. It is believed advisable to restrict the name allemontite to the component "B" rather than to apply it to the intergrowth of "A" and "B" as proposed by Van der Veen.

THE RELATIONSHIP BETWEEN THE STRUCTURAL AND MORPHOLOGICAL ELEMENTS OF KRENNERITE, CALAVERITE, AND SYLVANITE, by G. Tunell and C. J. Ksanda.

The structural lattices of krennerite, calaverite, and sylvanite have been determined by means of the Weissenberg x-ray goniometer. Although these three minerals all crystallize in different space-groups and the unit cells of the three minerals are of different sizes and shapes and contain different numbers of atoms—the unit cell of krennerite contains 8 "molecules" of  $\text{AuTe}_2$ , that of calaverite, 2 "molecules" of  $\text{AuTe}_2$ —and that of sylvanite 2 "molecules" of  $\text{AuAgTe}_4$ —a very close and simple relationship has been found between the three structural lattices. In krennerite and calaverite there is also a small amount of silver present in solid solution; in sylvanite there is a small amount of gold present in solid solution; thus the actual compositions of the three minerals as found differ slightly from the compositions of the pure end-members mentioned in the preceding sentence. The relationship between the morphological axial elements previously used and the new röntgenographic axial elements for the three minerals has also been established.

THE CRYSTAL STRUCTURE OF THE ARSENOPYRITE GROUP, by M. J. Buerger.

Members of the arsenopyrite group have the following cells each containing 8 formula weights:

	Arsenopyrite, Franklin, N.J. (rotations and oscillations)	Arsenopyrite, Spindel- mühle, Bohemia. (Weissenberg)	Gudmundite, Gudmund- storp, Sweden. (Weissenberg)
$a =$	6.42 Å	6.41 Å	6.68 Å
$b =$	9.55	9.51	10.04
$c =$	5.71	5.65	5.93

The diffraction effect symbol for the material used is definitely  $\text{mmmC} - - -$ , which would require either space group  $\text{Cmmm}$ ,  $\text{Cmm}$ , or  $\text{C222}$  (possibly  $\text{C222}_1$ ).  $\frac{1}{2}a$ ,  $\frac{1}{2}b$ , and  $c$  for arsenopyrite correspond closely with the mean marcasite-löllingite  $a$ ,  $b$ , and  $c$  respectively; the same relation holds between the dimensions of gudmundite and the mean of the marcasite— $\text{FeSb}_2$  axes. Certain intensity series also correspond between double salt and simple salt: thus, arsenopyrite and marcasite types of structures are characterized by a series of approximately equally spaced (100) sheets of duplicate atomic population. It is thus virtually certain that the arsenopyrite group has the general marcasite type of packing. No marcasite structural type, however, nor any simple modification of it, can be fitted into any of the space groups included in the diffraction symbol. On the other hand, a marcasite-like structure can be developed from one of the several subgroups of less than orthorhombic symmetry, namely:  $\text{C2/m}$ ,  $\text{C2}$ ,  $\text{Cm}$ ,  $\text{C}\bar{1}$ , or  $\text{C1}$  (possibly  $\text{C2}_1/\text{m}$ , and  $\text{C2}_1$ ). It follows as a consequence that the arsenopyrite group is of probable monoclinic or lower symmetry and, since orthorhombic symmetry is indicated in Weissenberg and Laue photographs, the crystals are not individuals, but consist of polysynthetically twinned aggregates. The actual existence of the twinned lamellar structure has been confirmed by etching and by observation of polished crystal surfaces in reflected polarized light.

The crystal structure appears to be based upon  $\text{C}\bar{1}$ , in which the sulfur pairs of marcasite are proxied by arsenic and sulfur or by  $\text{AsS}$  pairs. Structures with somewhat similar characteristics can be developed from  $\text{C2}$  and  $\text{Cm}$  but are less likely from bonding considerations.

## CRYSTALLOGRAPHY OF THE VIVIANITE GROUP, by Tom. F. W. Barth.

By optical goniometry the crystallographic constants of a mineral can be established only if a sufficient number of external faces is developed. If there are few or poorly developed faces no values, or uncertain values for the constants will result.

By using an  $x$ -ray goniometer accurate values can be obtained even though no external faces may be present. As seen from Table 1, the accuracy of the  $x$ -ray method is quite satisfactory. It is believed that greater accuracy can be secured with the reflection goniometer only if the crystal faces are of a high degree of excellence. The most accurate values for erythrite are therefore believed to be those obtained with the  $x$ -ray goniometer.

Some of the other members of the vivianite family are encountered in such imperfect crystals that no determinations of the crystallographic constants have been attempted. For other members the constants were known only approximately.

New  $x$ -ray measurements on this series of minerals have been conducted, and the crystallographic constants of the several members established. In addition to the axial ratio,  $a:b:c$ , the  $x$ -ray measurements give the absolute dimensions of the unit cell,  $a_0$ ,  $b_0$ ,  $c_0$ . In usual crystallographic orientation of these crystals we have:  $a:b:c=f(a_0, b_0, c_0)$ . This relation will be discussed in a forthcoming publication.

TABLE 1  
Crystallographic Elements of Vivianite and Erythrite

	$a$	$b$	$c$	$\beta$	Author
Vivianite	0.7488	1	0.7020	$104^\circ 33\frac{1}{2}'$	Cesàro
	0.7498	1	0.7017	$104^\circ 26'$	Goldschmidt
	0.7499	1	0.6996	$104^\circ 18'$	Barth ( $x$ -ray)
Erythrite	0.7502	1	0.7006	$105^\circ 01'$	Green
	0.7648	1	0.7122	$105^\circ 02'$	Barth (optical)
	0.7634	1	0.7092	$105^\circ 01'$	Barth ( $x$ -ray)

## CRYSTALLOGRAPHY OF LIVINGSTONITE, by Wallace E. Richmond, Jr.

Goniometric and röntgenographic measurements on livingstonite from the type locality, Huitzoco, Mexico—the first to be made on this mineral—give the following result. Monoclinic, holohedral;  $a:b:c=3.758:1:5.366$ ,  $\beta=104^\circ 10'$  (reflecting goniometer); forms,  $a(100)$ ,  $c(100)$ ,  $d(101)$ ,  $e(\bar{1}01)$ ,  $p(\bar{1}11)$ ,  $q(122)$ ; habit, acicular parallel to  $[010]$ ; cleavage,  $(001)$ , perfect; lustre, submetallic with internal reflections. Unit cell,  $a_0=15.14$ ,  $b_0=3.98$ ,  $c_0=21.60$ ,  $\beta=104^\circ$ , giving  $a_0:b_0:c_0=3.804:1:5.427$ . Using Dana's formula  $\text{HgSb}_4\text{S}_7$ , and density 4.81, the cell contents are  $\text{Hg}_4\text{Sb}_{16}\text{S}_{28}$ .

## CALCITE TWINS FROM NORTH PLAINFIELD, NEW JERSEY, by Alfred C. Hawkins.

Two heart-shaped calcite twins showing identical forms occurred together in a cavity along a fault-zone in the basalt of First Watchung Mountain.

Twinning plane is the minus rhombohedron  $e(01\bar{1}2)$  and the forms shown on the crystals are scalenohedrons and rhombohedrons. They will be described.

## SOME NOTES ON THE STRUCTURE OF STILPNOMELANE, by John W. Gruner.

Eight analyses of stilpnomelane suggest the formula  $(\text{OH})_{26}\text{K}(\text{Fe}''\text{Mg})_9(\text{Fe}'''\text{Al})_{5.6}\text{Si}_{14}\text{O}_{39.40}$ .

Five of the eight were  $x$ -rayed, three of them not being available. The photographs suggest a layer structure similar to chlorite and mica with the following dimensions  $a_0=5.4\text{\AA}$ ,  $b_0=9.3\text{\AA}$ ,  $c_0=24.1\text{\AA}$ . This unit cell contains two molecules of the formula above.

So far it has been impossible to arrange sheets of the mica, brucite, or kaolinite type in such a way that the intensities of the basal reflections of the photographs can be explained satisfactorily. Very many plausible combinations have been tried. Also heating of the mineral up to 740°C. has offered no clue. It is stable at temperatures at least as high as 560°C, but its structure is destroyed at 740°C.

#### THE CRYSTAL STRUCTURE OF CUBANITE, by M. J. Buerger.

An equi-inclination Weissenberg study of cubanite leads to the following data:

Diffraction symbol: mmmPc-n

Space group: Pcmn =  $V_h^{16}$ , on the basis of holohedral morphological development.

Unit cell, corrected to Peacock's axial ratio:

$$a = 6.45\text{\AA}$$

$$b = 11.07$$

$$c = 6.21$$

$$Z = 4 \text{ formula weights per unit cell.}$$

The following structure, based upon a substituted wurtzite framework, is proposed:  
in 4c

	$u_a$	$v_c$
Cu	$\frac{11}{12} + \delta_1$	$\frac{1}{12} + \delta_2$
SI	$\frac{11}{12} + \delta_3$	$\frac{5}{12} + \delta_4$

in 8d

	$x_a$	$y_b$	$z_c$
Fe	$\frac{5}{12} + \delta_5$	$\frac{1}{12} + \delta_6$	$\frac{1}{12} + \delta_7$
SII	$\frac{5}{12} + \delta_8$	$\frac{1}{12} + \delta_9$	$\frac{5}{12} + \delta_{10}$

where the  $\delta$ 's are small corrections necessary to improve the intensity fit. All atoms have tetrahedral co-ordinations. A unique feature of the structure is the occurrence of the iron atoms in pairs; the vectors connecting the pairs have greatest components in the direction of the  $b$ -axis. This is believed to be responsible for the ferromagnetism of cubanite, whose magnetic axis is the  $b$ -axis.

#### THE PROBABLE IDENTITY OF THE STRUCTURES OF GREENALITE (MESABI RANGE), by John W. Gruner.

Four samples of greenalite from different points on the Mesabi range were carefully cleaned by the dialectric method. X-ray photographs of their powders were compared with those of various serpentines. The agreement between the diagrams of these two minerals is so good that their structures must be alike. A theoretically pure iron serpentine would have the composition  $\text{SiO}_2 = 32.3$ ,  $\text{Fe} = 58.0$ , and  $\text{H}_2\text{O} = 9.7$ . These figures agree closely with the analyses by Leith (U. S. Geol. Survey Mon. 43), but not at all with those by Joliffe (Am. Mineral., vol. 20, p. 418).

#### THE CRYSTAL STRUCTURE OF BERTHIERITE, by M. J. Buerger.

The original Kisbanya, Carpathian, berthierite described by Zsivny and Zombory has been studied by the equi-inclination Weissenberg method. This investigation leads to the following data:

Diffraction symbol: mmmPna-.

Space group (as a result of intensity considerations): Pnam =  $V_h^{16}$ .

Unit cell: absolute ratio

$$a = 11.44\text{\AA} \quad .810$$

$$b = 14.12 \quad 1.$$

$$c = 3.76 \quad .2663$$

$Z = 4$  formula weights per unit cell; excess iron and antimony shown by the chemical analysis is housed in interstitial solid solution.

The following structure, based upon a substituted diamond framework, is proposed: all atoms in  $4c$ , with following parameters:

	$u_a$	$v_b$
Fe	$\frac{1}{16} + \delta_1$	$\frac{1}{4} + \delta_2$
Sb <sub>I</sub>	$\frac{3}{16} + \delta_3$	$-\frac{1}{8} + \delta_4$
Sb <sub>II</sub>	$\frac{3}{16} + \delta_5$	$-\frac{3}{8} + \delta_6$
S <sub>I</sub>	$\frac{1}{16} + \delta_7$	$0 + \delta_8$
S <sub>II</sub>	$\frac{3}{16} + \delta_9$	$\frac{1}{8} + \delta_{10}$
S <sub>III</sub>	$\frac{3}{16} + \delta_{11}$	$\frac{3}{8} + \delta_{12}$
S <sub>IV</sub>	$\frac{1}{16} + \delta_{13}$	$-\frac{1}{4} + \delta_{14}$

where the  $\delta$ 's are small corrections necessary to improve the intensity fit. Fe, Sb<sub>I</sub>, S<sub>I</sub>, S<sub>II</sub>, and S<sub>IV</sub> have tetrahedral co-ordination, while Sb<sub>II</sub> and S<sub>III</sub> have trigonal co-ordination at tetrahedral angles.

The structure is characterized by empty channels parallel with the  $c$  axis. Presumably the interstitial solid solution has its origin in this feature.

#### THE CRYSTAL STRUCTURE OF VALENTINITE, by M. J. Buerger.

An equi-inclination Weissenberg study of both natural valentinite from the Su Suergiu mine, Sardinia, and of artificial valentinite made by subliming chemically pure Sb<sub>2</sub>O<sub>3</sub> in an atmosphere of nitrogen, leads to the following data:

Diffraction symbol:  $mmmPc\bar{c}n$

Crystal class: definitely orthorhombic holohedral because of three detectable glide planes.

Space group:  $Pc\bar{c}n = V_h^{10}$ .

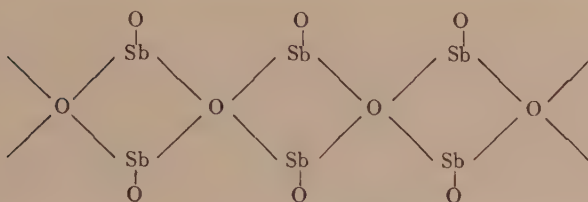
Unit cell:

	absolute	ratio
$a =$	4.92	.395
$b =$	12.46	1.
$c =$	5.42	4.35
$Z = 4 \text{ Sb}_2\text{O}_3 \text{ per unit cell.}$		
$d = 5.75$		

The structure has been determined by straightforward methods. The antimony atoms are in the general position,  $8c$ , with parameters  $x_a = .1215$ ,  $y_b = .207$ ,  $z_c = .175$ .

One-third of the oxygen atoms are on the two-fold axes,  $4c$ , with parameter,  $u_c = -.075$ . The other two-thirds of the oxygen atoms are in the general position with parameters which can be determined only approximately:  $x_a = -.11$ ,  $y_b = .156$ ,  $z_c = .175$ . The structure consists of rather isolated strings of





extending indefinitely in the direction of the *c* axis. The structure accounts well for the perfect cleavages in the prismatic zone.

A TABULATION OF CRYSTAL FORMS AND DISCUSSION OF FORM-NAMES, by Austin F. Rogers.

The Fedorov method of naming forms according to the number and shape of faces rather than by their position with respect to axes of reference is advocated.

A convenient tabulation of the 48 possible forms is presented in which open and closed, variable and invariable, and general and limit, forms are distinguished.

There are supplementary tables in which the derivation of general and limit forms is indicated.

This occasion offers an opportunity of discussing the various form-names.

THE ACCESSORY MINERALS OF THE WOLF MOUNTAIN GRANITE, by R. E. McAdams.

This paper is a report of an investigation of the accessory minerals of the Wolf Mountain phacolith and other intrusive masses of central Texas. The Wolf Mountain granite and a nearby granite (Lone Grove) are characterized by apatite, zircon, titanite and monazite. Other intrusives thought to be younger contain fluorite as a prominent accessory.

The distribution of zircon and apatite in the Wolf Mountain intrusive suggests that the mass is of phacolithic habit rather than batholithic as suggested by some investigators.

With no further business to come before the Society, President Clarence S. Ross declared the meeting adjourned at 12 noon.

At various times during the sessions of the Society, the following persons registered their attendance. In addition there were many others who visited sessions whose names were not recorded.

H. R. Aldrich  
F. I. Allen  
H. L. Alling  
O. Andersen  
G. H. Anderson  
R. J. Anderson  
E. J. Armstrong

R. Balk  
Mrs. R. Balk  
H. M. Bannerman  
J. D. Barksdale  
T. Barth  
F. Bascom

B. F. Buie  
L. H. Bauer  
W. S. Bayley  
C. H. Behre, Jr.  
J. F. Bell  
H. Berman  
F. Betz, Jr.  
M. Billings  
P. H. Bird  
R. G. Bispham  
R. G. Bogue  
V. H. Booth  
M. N. Bramlette  
D. Brauneck

L. S. Brown  
R. M. Brown  
E. L. Bruce  
A. F. Buddington  
P. B. Bunton  
W. S. Burbank  
J. D. Burfoot, Jr.  
B. T. Butler  
J. W. Butler  
  
C. K. Cabeen  
E. Callaghan  
W. H. Callahan  
E. N. Cameron

- |                 |                      |                   |
|-----------------|----------------------|-------------------|
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| L. V. Case      | J. W. Greig          | Mrs. E. S. Larsen |
| C. A. Chapman   | R. E. Grim           | E. Larson, III    |
| R. W. Chapman   | F. F. Grout          | O. I. Lee         |
| H. D. Chase     | E. M. Gunnell        | G. D. Louderback  |
| D. B. Chisholm  |                      | G. F. Loughlin    |
| W. B. Colburn   | J. B. Hadley         | T. S. Lovering    |
| C. S. Corbett   | J. C. Haff           | J. Lowe           |
| A. Creagh       | C. H. Hale, Jr.      |                   |
| G. W. Crickman  | Mrs. C. H. Hale, Jr. | H. E. McKinstry   |
| L. W. Currier   | G. M. Hall           | J. P. Marble      |
|                 | B. Hamilton          | E. B. Mathews     |
| R. Daly         | J. B. Hanley         | J. E. Maynard     |
| D. W. Davis     | W. C. Hatfield       | E. B. Mayo        |
| A. L. Day       | A. C. Hawkins        | E. Mencher        |
| P. F. Dickson   | F. L. Hess           | A. Messina        |
| J. D. H. Donnay | H. H. Hess           | B. L. Miller      |
| L. Dorschel     | D. F. Hewett         | C. Milton         |
|                 | G. R. Heyl           | A. Minkofsky      |
| M. L. Ehrmann   | T. M. Hills          | A. Montgomery     |
| J. D. Eisler    | R. J. Holmes         | E. S. Moore       |
|                 | A. P. Honess         | G. W. Morey       |
| E. E. Fairbanks | M. Hooker            | F. K. Morris      |
| F. W. Farwell   | A. D. Howard         | J. F. Morton      |
| G. T. Faust     | W. V. Howard         | R. E. Myers       |
| C. N. Fenner    | S. G. Hower          |                   |
| H. G. Ferguson  | A. L. Howland        | P. J. Nekrasoff   |
| C. R. Fettke    | W. F. Hunt           | D. A. Nichols     |
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| G. I. Finlay    | C. S. Hurlbut        |                   |
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| F. C. Foley     | W. H. Irwin          |                   |
| M. E. Forde     |                      | C. Palache        |
| W. F. Foshag    | E. C. Jacobs         | M. A. Peacock     |
| K. Fowler-Lunn  | C. P. Jenney         | J. W. Peoples     |
| E. J. Foyles    | J. H. Johnson        | E. L. Perry       |
| D. M. Fraser    | J. R. Jones          | S. S. Philbrick   |
| A. H. Fretz     | M. L. Jones          | A. H. Phillips    |
| C. Frondel      |                      | A. W. Pinger      |
|                 | P. F. Kerr           | M. B. Pollack     |
| A. Gabriel      | Mrs. P. F. Kerr      | F. H. Pough       |
| R. B. Gage      | J. Kessler           |                   |
| D. L. Gamble    | A. Knopf             | D. Randolph       |
| J. L. Gillson   | Mrs. A. Knopf        | H. L. Rickard     |
| J. Gilluly      | R. B. Koehler        | H. Ries           |
| J. J. Glass     | E. H. Kraus          | A. F. Rogers      |
| E. N. Goddard   | P. Krieger           | J. L. Rosenholtz  |
| F. A. Gonyer    |                      | R. R. Rosenkrans  |
| S. G. Gordon    | A. C. Lane           | C. S. Ross        |

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M. Runne	M. H. Stow	C. H. Warren
	B. Stringham	A. C. Waters
E. S. Salmon	J. L. Stuckey	E. Weidhaas
E. Sampson	M. N. Sutherland, Jr.	A. M. Wellnitz
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W. T. Schaller	S. Taber	A. W. Weston
Mrs. W. T. Schaller	E. Thomson	E. T. Wherry
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Q. D. Singewald	D. W. Trainer, Jr.	A. N. Winchell
C. B. Slawson	G. Tunell	Mrs. A. N. Winchell
D. T. Smith		A. E. Woods
I. F. Smith	R. C. Vance	F. E. Wright
A. K. Snelgrove	S. Varni	
R. B. Sosman		P. Zodac

## LIST OF FORMER OFFICERS AND MEETINGS WITH DATES

By recommendation of the Council, a complete list of past officers is printed in the proceedings of the annual meeting of the Society.

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1921	Charles Palache
1922	Thomas L. Walker
1923	Edgar T. Wherry
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1927	Austin F. Rogers
1928	Esper S. Larsen
1929	Arthur L. Parsons
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1935	Clarence S. Ross

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1923-1933	Frank R. Van Horn
1933-1934	Albert B. Peck
1934-	Paul F. Kerr

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1924-1929	Alexander H. Phillips
1929-1930	Albert P. Beck
1931-	Waldemar T. Schaller

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1920-1921 Edgar T. Wherry

1922- Walter F. Hunt

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1922 Fred E. Wright, Alexander H. Phillips, Austin F. Rogers, Thomas L. Watson.  
1923 Alexander H. Phillips, Austin F. Rogers, Thomas L. Watson, Esper S. Larsen.  
1924 Austin F. Rogers, Thomas L. Watson, Esper S. Larsen, Arthur L. Parsons.  
1925 Thomas L. Watson, Esper S. Larsen, Arthur L. Parsons, William F. Foshag.  
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1927 Arthur L. Parsons, William F. Foshag, William A. Tarr, Alexander N. Winchell.  
1928 William F. Foshag, William A. Tarr, Alexander N. Winchell, Ellis Thomson.  
1929 William A. Tarr, Alexander N. Winchell, Ellis Thomson, Clarence S. Ross.  
1930 Alexander N. Winchell, Ellis Thomson, Clarence S. Ross, Paul F. Kerr.  
1931 Ellis Thomson, Clarence S. Ross, Paul F. Kerr, William S. Bayley.  
1932 Clarence S. Ross, Paul F. Kerr, William S. Bayley, William J. McCaughey.  
1933 Paul F. Kerr, William S. Bayley, William J. McCaughey, Kenneth K. Landes.  
1934 William S. Bayley, William J. McCaughey, Kenneth K. Landes, E. P. Henderson.  
1935 William J. McCaughey, Kenneth K. Landes, Edward P. Henderson, J. F. Schairer.

## ANNUAL MEETING PLACES

- 1920 Chicago, Illinois  
1921 Amherst, Massachusetts  
1922 Ann Arbor, Michigan  
1923 Washington, D. C.  
1924 Ithaca, New York  
1925 New Haven, Connecticut  
1926 Madison, Wisconsin  
1927 Cleveland, Ohio  
1928 New York, New York  
1929 Washington, D. C.  
1930 Toronto, Canada  
1931 Tulsa, Oklahoma  
1932 Cambridge, Massachusetts  
1933 Chicago, Illinois  
1934 Rochester, New York  
1935 New York, New York



## BOOK REVIEW

LES MINÉRAUX ET LES ROCHES, ÉTUDES PRATIQUES DE CRISTALLOGRAPHIE, PÉTROGRAPHIE ET MINÉRALOGIE, 6<sup>e</sup> ÉDITION. H. BUTTGENBACH. Professeur à l'Université de Liège, Membre de l'Académie royale de Belgique, de l'Institut royal colonial belge et de l'Académie des sciences coloniales de Paris. Paris, Dunod, éditeur, 92, rue Bonaparte (VI<sup>e</sup>). Liège, Vaillant-Carmanne, imprimeur, 4, place St. Michel. 1935. Printed in Belgium. XII+730 pp., 16 by 24 cm., 609 figs., 4 pls. Bound in half cloth.

When an author decides to write a *practical* textbook, he is apt to stress the facts rather than their explanation, to omit the proof of the theorems, and to present results without adequate derivation. The outcome of such a procedure is at best a catalogue of rules of thumb, or mnemonic recipes, by means of which a student is expected to find his way through a maze of disconnected phenomena. Buttgenbach's self-styled "practical studies of crystallography, petrography, and mineralogy" proceed from a wholly different viewpoint, giving eloquent proof that a practical approach to the subject can be handled in a scientific way. The policy adopted is to outline the fundamentals in such a manner as to provide methods of reasoning that can be applied in determinative work. The new edition (the 6th since the war) strives in this direction with even more success than the preceding ones. The aim, for fact, is fully realized.

The author is well qualified to understand, and to meet the needs of the practical man. He has long been active in colonial prospecting and development; since 1921, when he succeeded his former professor G. Cesàro, he has been teaching at the University of Liège. The influence of his own field experience, and that of Cesàro's teaching, can be sensed throughout the book.

The crystallography (roughly 300 pages) is largely that of the French School. The bulk of mathematical proof is collected in a separate section (*Compléments*), which may make it easier to read the text proper. A few salient features may be mentioned: (1) Derivation of crystal forms by truncations of the Lévy "primitives," use of merohedry, and the so-called Law of Symmetry. Only crystal classes of practical interest are studied in detail; all 32 are listed, however. Alternating symmetry is merely mentioned for the sake of completeness. (2) In harmony with the truncation method, the logical Haüy-Lévy form symbols are exclusively used for descriptive purposes; in the tetragonal system the primitive form is placed with the prism faces parallel to the Miller axes, thus avoiding unnecessary complication.<sup>1</sup> (3) Although the symmetry of the lattice is made the basis for the division into 7 systems, the 5 trigonal classes are considered only as rhombohedral, never as hexagonal. (4) The Miller symbols are used only in calculations. The choice of co-ordinates axes, therefore, is less important from the standpoint of symmetry than it is for crystallographers who use the Miller symbols exclusively. Three axes ( $xyz$ ), right-handed, are used in the hexagonal system; they are obtained by omitting the 3rd horizontal axis of the Bravais set ( $xyuz$ ). The faces of the hexagonal protoprism are then written: (100), (010), ( $\bar{1}10$ ), . . . instead of: (10 $\bar{1}$ 0), (01 $\bar{1}$ 0), ( $\bar{1}100$ ), . . . In the rhombohedral system, a left-handed set ( $xyz$ ) is used, corresponding to ( $\bar{u}xz$ ) of the Bravais set. The symbols of the rhombohedral faces are: (111), ( $\bar{1}01$ ), (0 $\bar{1}1$ ), . . . instead of (100), (010), (001), . . . in the Miller axes, or (10 $\bar{1}1$ ), (0 $\bar{1}11$ ), ( $\bar{1}101$ ), . . . in the Bravais axes. Faces of the same crystal form thus do not show their symmetry by cyclic permutation of indices. This does not

<sup>1</sup> If the Lévy notation were likewise "Millerized" in the trimetric systems, it would probably be, at least in its simplified form, the best set of significant letters our Nomenclature Committee could hope for. (Note of the reviewer.)

matter (in Buttgenbach's treatment) since the Lévy form symbols are to be determined anyway at the close of the calculations. (5) Knowledge of spherical trigonometry (taught in secondary schools in Belgium) in presupposed. One-circle goniometry is used. It is interesting to note that the first step recommended in crystal calculation is to determine the  $\phi$  and  $\rho$  of all faces and poles of coordinate axes, whence a straightforward solution follows, even in triclinic cases. (6) Stereographic projection is fully explained. (7) Worthy of mention is a very simple derivation of the general formulae for the angle between two faces, in terms of their Miller indices and axial elements of the crystal. (8) The statement that the law of rationality does not imply simplicity of indices (p. 103) will be questioned by many who regard simplicity of indices as the very law. (9) As to the chapter on twinning, it seems unfortunate that no mention of Friedel's generalized explanation is given; the *groupements de complément* could be more accurately described in the light of the Friedel theory. (10) The treatment of crystal optics is truly remarkable for its simplicity and logic, chiefly due to the exclusive use of the index ellipsoid as the only optical surface.<sup>2</sup> Its derivation is based on the elasticity theory. (11) Refractive indices are designated by  $n_p$ ,  $n_m$ ,  $n_g$  in the theoretical part, and by  $\alpha$ ,  $\beta$ ,  $\gamma$  (courteous compromise!) in the descriptive section. (12) Many more specialized topics have been added or revised, *viz.*: universal stage, reflected light, magnetic and electric properties, x-rays, radioactivity, mechanical properties, isomorphism, etc. The major principles are outlined in each case; the book can thus touch on a large number of subjects related to mineralogy, so as to satisfy or (which is just as well!) arouse the curiosity of the reader.

The second and third parts (petrography 50 pages, and metallogeny 20 pages) are essentially given as an aid for the understanding of mineralogy; they offer an excellent summary of the general rules covering the occurrence, genesis, and alteration of minerals. The section on igneous rocks is recast. The French classification is used, but the C.I.P.W. method is also explained and some classification problems worked out.

The descriptive mineralogy covers nearly 300 pages and includes well over 300 minerals. The index lists over 800 mineral- and rock-names. Many species have been added. The choice has been made so as to embrace: all minerals of crystallographic or petrographic importance, minerals having industrial usefulness, minerals found in association with the more common species, and finally all minerals from Belgium or the Congo (the latter are the author's special field). Dana's chemical classification is followed. The Lévy notation is universally used because of its descriptive value. The figures are excellent, in spite of their free-hand lettering. Most crystal drawings are in cavalier perspective. Appropriate sketches illustrate the optical orientation. Distinguishing features are given for every species. All chemical characters mentioned have been checked (by J. Mélon) for each mineral.

The chapter on the determination of minerals has been revised. The appended determinative tables are an attractive feature of the book, especially Table VIII, which divides 134 cleavable minerals, according to the optical appearance of cleavage plates in convergent light, into 7 groups further subdivided by the optic sign of the mineral, maximum birefringence, cleavage birefringence, refractive index, and optic angle (2V and 2e). Examination of cleavage flakes as an aid in mineral determination is a tradition at the School of Liège; Buttgenbach was the first to publish the data in tabular form; the table has been expanded in the 6th edition. Table IX is a handy dichotomous key for the determination of about 40 rock-forming minerals. An alphabetical index for minerals and rocks is appended.

<sup>2</sup> Although the sole use of this indicatrix has been advocated in the English literature (Fletcher, F. E. Wright), the proposal has not been generally followed in our textbooks. I use the method in my course and find it most satisfactory. (Note of the reviewer.)



The book is very well printed, slightly marred by some inevitable typographical errors. It is cheaply bound, but can be procured in any type of binding.

It may be safely predicted that this new edition will enjoy the wide popularity of its predecessors.

J. D. H. DONNAY

## NOTES AND NEWS

The Magazine *Rocks and Minerals* of Peekskill, New York, is sponsoring a mineralogical tour through Norway from July 4 to Aug. 13, 1936. Ample opportunity will be given to visit the famous mineral localities and to collect specimens. The Open Road, 8 West 40th St., New York City, will have charge of travel and business arrangements. While the rate of \$382 includes steamship passage in Third Class, Tourist Class accommodation may be secured at an additional charge of \$49. Those desiring further information should address Mr. Richmond E. Myers, 222 E. Union St., Bethlehem, Pa., who will serve as Director of the tour.

Professor W. J. McCaughey, Chairman of the Department of Mineralogy, at Ohio State University, has been selected as the Edward Orton, Jr., Fellow Lecturer for 1936. Dr. McCaughey is an eminent authority on the application of petrographic methods to the study of ceramic materials. "Contribution of mineralogy to ceramic technology and ceramic research" has been chosen as the title of the lecture which will be given on March 31 before the American Ceramic Society which is to hold its annual meeting at Columbus, Ohio.

## TEACHING FELLOWSHIP IN MINERALOGY

A teaching fellowship in mineralogy has been established at Stanford University. The fellowship is open to graduate students who intend to specialize in mineralogy, and preference will be given to those who have had one or two years of graduate work. The chief duty of the fellow is to assist in laboratory instruction. Not more than eight or nine hours work a week will be required. The amount of the fellowship is \$750.

Application for the year 1936-37, accompanied by testimonial letters, should be made to Professor Austin F. Rogers, Box 87, Stanford University, California.

## Correction

The theoretical composition to correspond to the formula given in Column 4, Table 4 (Analyses of vesuvianite), page 8, January issue of *The American Mineralogist*, should read:

SiO <sub>2</sub>	37.89
Al <sub>2</sub> O <sub>3</sub>	14.29
FeO	0.75
MgO	5.23
CaO	39.31
H <sub>2</sub> O	2.53

## NEW MINERAL NAMES

### Beiyinite

T. L. Ho: Note on some rare earth minerals from Beiyin Obo, Suiyuan: *Bull. Geol. Soc. China.*, vol. 14, No. 2, pp. 279-282, 1935.

NAME: From the locality Beiyin Obo.

CHEMICAL PROPERTIES: Perhaps a lanthanum, cerium, yttrium, erbium-bearing mineral. Insoluble in HCl; soluble with difficulty in hot concentrated  $H_2SO_4$  with effervescence; infusible.

PHYSICAL AND OPTICAL PROPERTIES: Color, greenish yellow in thin-section with feeble pleochroism. Hd. about 4.5.  $G.=4.829$ ; cleavage, basal perfect. Uniaxial negative.  $\omega=1.7169$ ,  $\epsilon=1.7910$ .

OCCURRENCE: Found as grains in fluorite veins at the iron ore deposits of Beiyin Obo, 150 Km., north of Paoto, Suiyuan, associated with fine grains of magnetite, pyrite, barite and oborite.

Resembles bastnaesite, except for lower index of extraordinary ray.

W. F. FOSHAG

### Oborite

T. L. Ho: *Ibid.*, pp. 279-282.

NAME: From the locality Beiyin Obo.

CHEMICAL PROPERTIES: Perhaps a lanthanum, cerium, yttrium, erbium mineral. Chemical reactions like beiyinite, but more insoluble.

CRYSTALLOGRAPHICAL PROPERTIES: Perhaps hexagonal.

PHYSICAL AND OPTICAL PROPERTIES: Color, greenish yellow in thin-section. Cleavage, perhaps rhombohedral, with  $0001 \wedge 10\bar{1}1 = 51.2^\circ$ . Hd. and G. like beiyinite.

OCCURRENCE: Like Beiyinite.

W. F. F.